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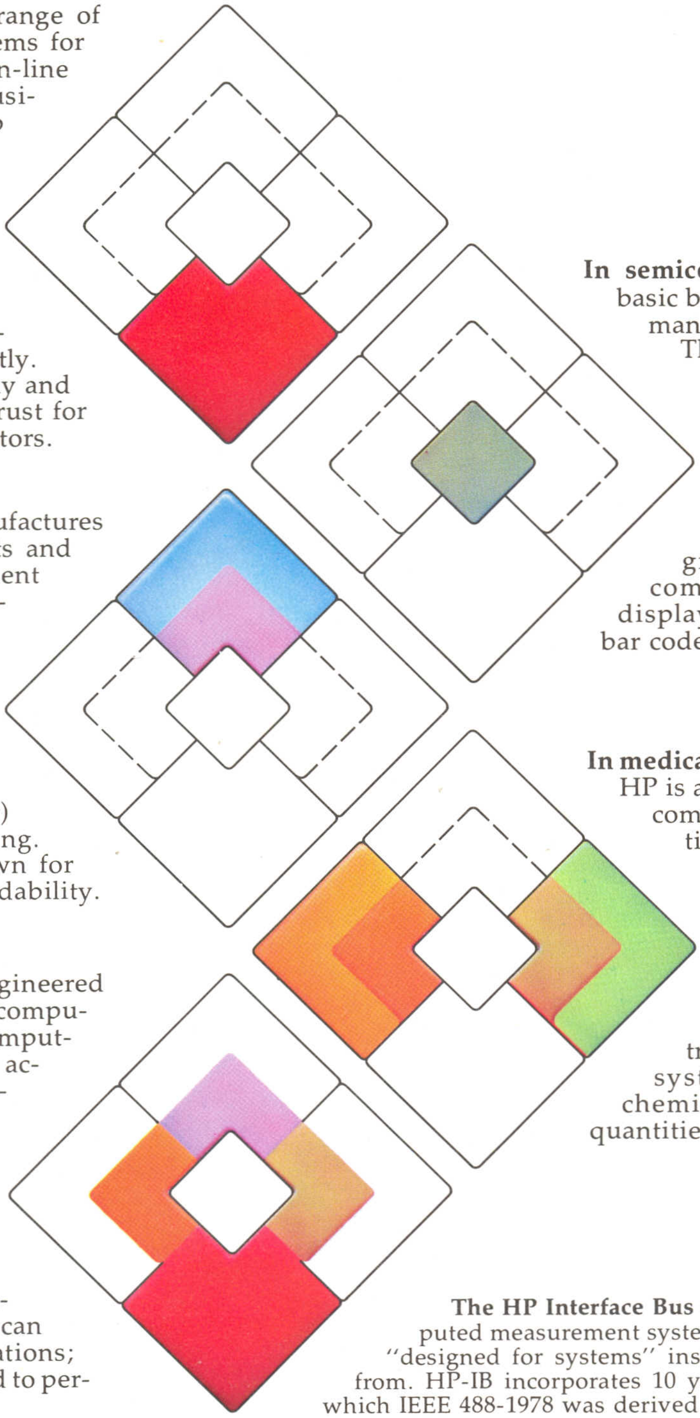

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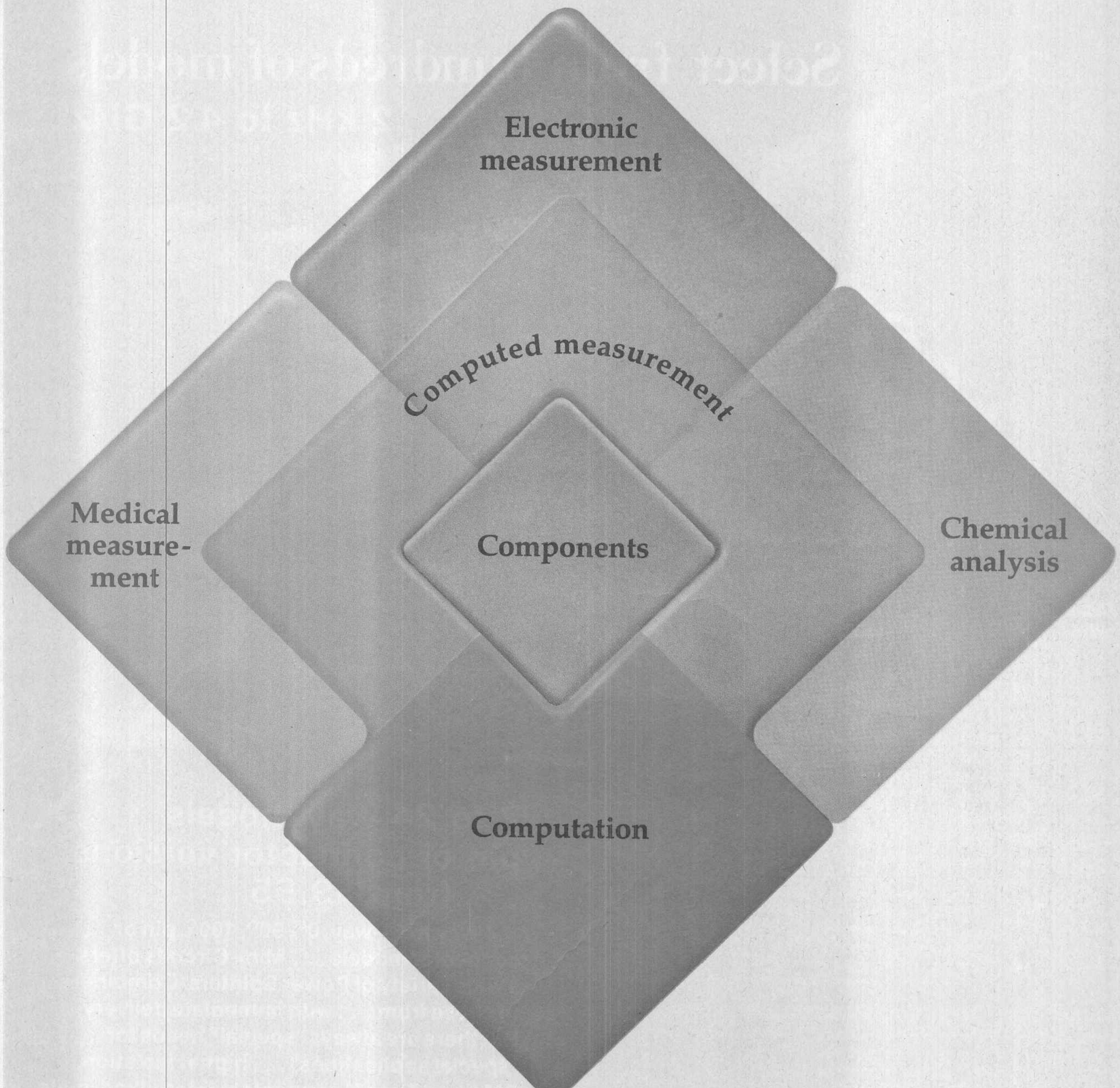

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Electronics
The International Magazine of Electronic Technology
Vol. 53, No. 9 • April 17, 1980

FIFTY YEARS OF ACHIEVEMENT: A HISTORY

Tinkerers and isolated experimenters started a new technology, nurtured by bold entrepreneurs and stimulated by society's needs.

LOOKING AHEAD TO THE YEAR 2000

Twenty years from now, profound changes will have been wrought in the technology, the engineering profession, and the structure of the industry.

Almost from the beginning, over a year ago, this anniversary issue became known as Project 50 among the editors of *Electronics*. It started with a series of meetings at which it was decided to include both a history and a detailed look at the future. Then at a full staff meeting last May the project was truly launched.

Everyone realized it would be a lot of work, but no one foresaw quite how time-consuming it would be.

Project 50 involved not only the entire *Electronics* staff, domestic and foreign, but also several free-lancers brought in to handle specific tasks such as digging up old photographs, checking facts, editing, preparing the index, and creating the cover. But on the whole, the regular staff did the sweating and writing while at the same time continuing to put out the regular issues of the magazine every two weeks.

Not surprisingly, the editors had a love-hate relationship with Project 50. On the love side, everyone became interested in the content. Those preparing the history discovered or rediscovered fascinating information from the past. Those peering into the future got caught up in the fascination of forecasting the next two decades. Our field bureaus interviewed scores of industry observers and planners for their views, who also enjoyed the opportunity of looking ahead.

The hate side of the relationship was well to the fore, too. At times the project seemed endless, and as with all long-term endeavors, deadlines were missed left and right. Editors who prided themselves on being fast writers found the Project 50 sections long and demanding. More than a few began referring to the effort as their life's work. And relatives and friends learned to endure the sudden cancellation of social plans.

A project of this nature always inspires a number of jokes and wisecracks. One of the best came from an outsider.

"The earlier you get behind on a project, the more time you have to catch up," he remarked. That maxim should endure.

The logistics of handling the manuscripts, the illustrations, and the typesetting were staggering as well. Also, all processing of the extra material had to be interwoven with the regular biweekly publication schedule, and the printing had to be interspersed with the printing of the regular issues.

Now that Project 50 has finally become the Special Commemorative Issue, we are tempted to speak of it in Hollywood terms: "Cast of thousands! Years in the making! The greatest spectacle of our times!" Hyperbole, certainly, though we are pleased with the result. As with a piece of electronic hardware developed over a long period, there is a certain thrill to learning that the finished product works. Tired we may be, but we are also proud.

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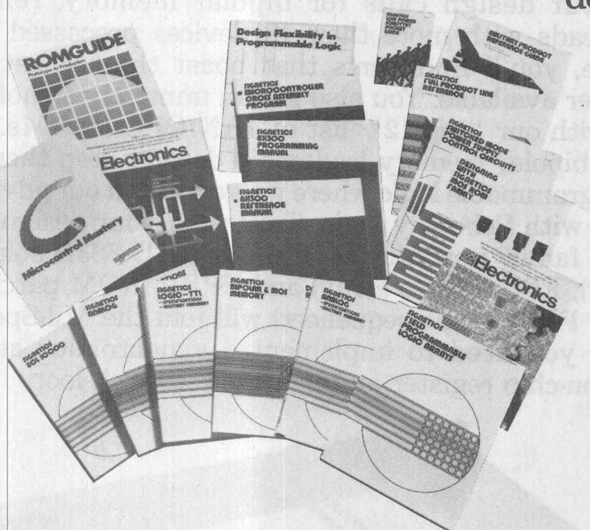

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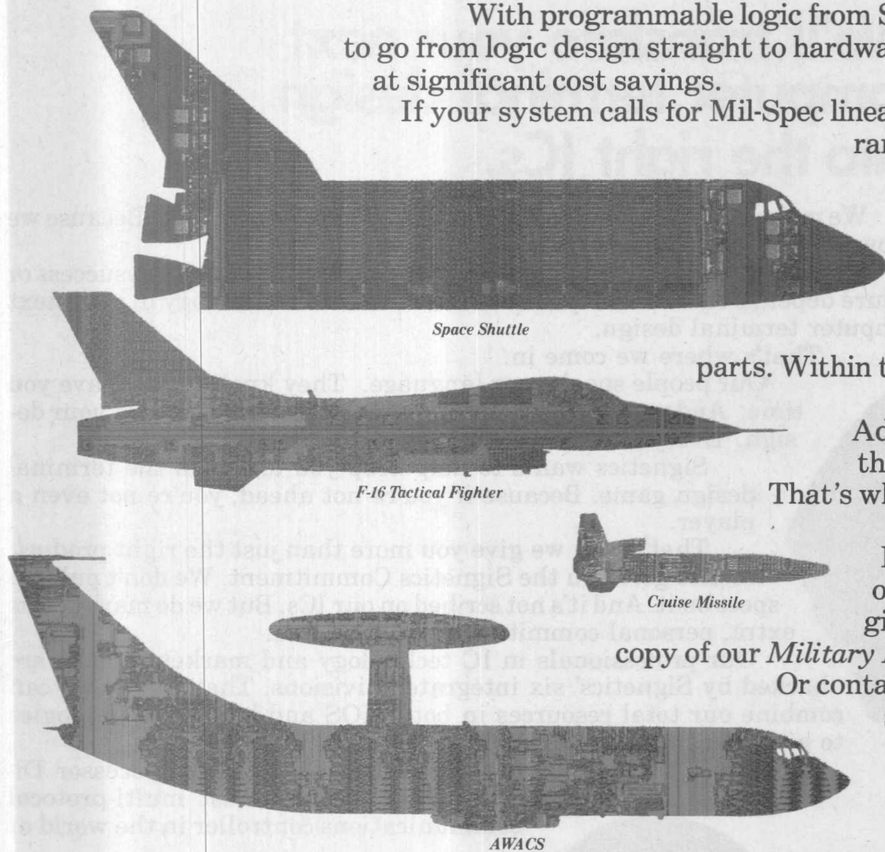

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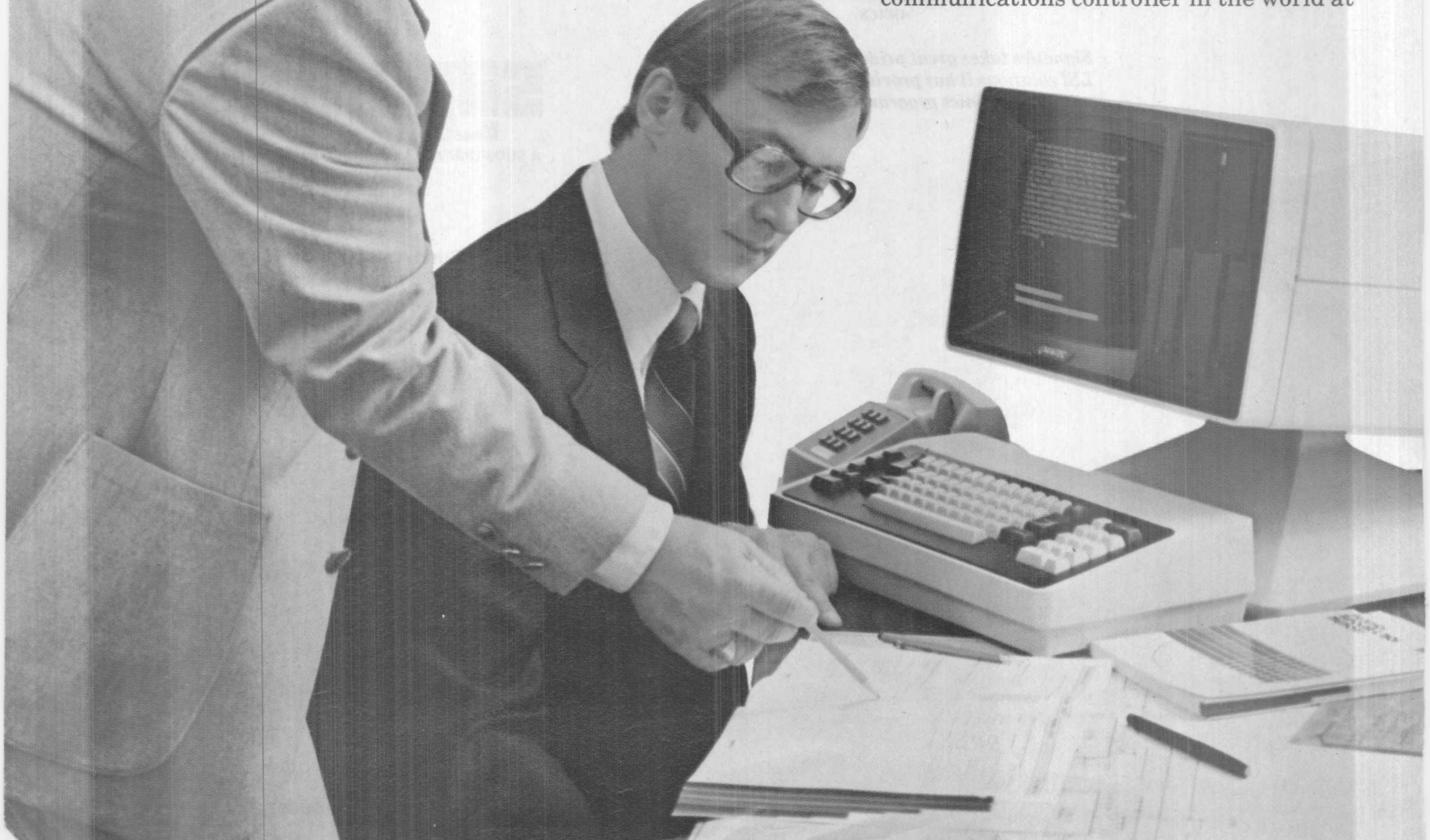

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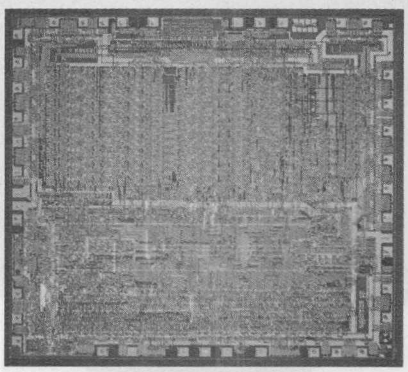

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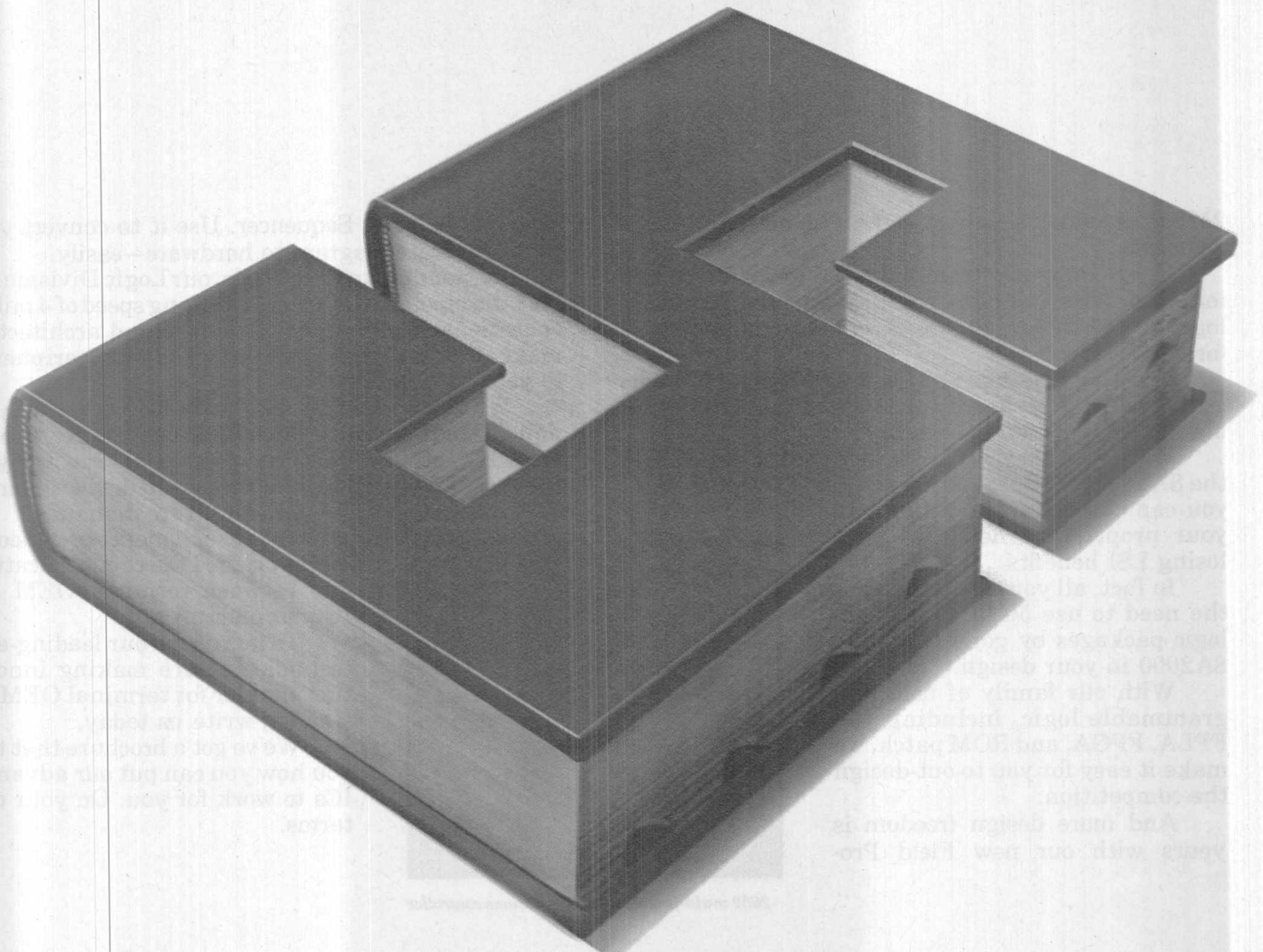

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50 YEARS

In April of 1930, O. H. Caldwell, the first editor of *Electronics*, outlined the new magazine's function in his editorial for its first issue.

"For this vital, pulsing electronic art a clearinghouse is needed—an engineering journal that will gather together these widespread activities; chronicle scientific and industrial advances abroad and here, and provide practical usable information which can be put to work," he wrote. "Such a journal must have scientific vision to look above and beyond the present; it must be courageous and devoted in its stand for progress and for expanding applications. . . .

"The art of the electron tubes goes forward to great and greater achievements. To the engineers and executives in all the ramified branches of electronics, the editors and publishers pledge a service worthy of this field of unparalleled opportunity."

Caldwell's words are old-fashioned and somewhat stilted. But they set a course for *Electronics* from which the magazine has never veered.

The issue you are about to read and, we hope, enjoy and cherish was conceived as a celebration of the first 50 years of *Electronics*' existence. But it has become more than that—it also celebrates a technological revolution that has transformed modern life. It is a testimonial to the enterprise and the imagination and the daring that have given rise to great companies and institutions and a mighty industry. And above all, it is a tribute to thousands of creative people, those engineers, scientists, and inventors, whose vision and energy have fueled the ever-accelerating progress of electronics over the past half century and promise to continue to do so into the foreseeable future.

A 50th anniversary is both an occasion to look backwards and an opportunity to look forward, and that's precisely what we've done. The task was simple on the surface—after all, we had an excellent archive in the form of the magazine itself—but it turned out to be massive and time-consuming. Planning started over a year ago, and the project ultimately involved all of the 40 or so editorial staff members in New York and around the world, supplemented by consultants to help in the research and editing required.

The history of electronics occupies about two thirds of this special issue. For a very few of our editors, it was a refreshing bout with nostalgia, reviving memories of the

exciting events that have pushed electronics into the pivotal position that it occupies in today's world. For most of our younger editors, it was a revelation, as they discovered that the manifestations of today's technology—television, computers, solid state—which they had seen as creations of their own time, had their roots in the dreams of men who labored long before they were born. And as you read on, I suspect that you, too, will share these mixed reactions of surprise and pleasurable recall.

The history has eight chapters. The first is a snapshot of the technological and sociological milieu of 1930—the setting in which *Electronics* was born—and the next explores the developments that led up to that point. The remaining six proceed roughly by decades, each dominated by some technological or sociological watershed. For example, Chapter 3 describes the Depression-ridden thirties; Chapter 4, the war years. The advent of solid-state technology in 1948 is of such monumental importance that Chapter 5 is devoted wholly to it and to the subsequent growth of the semiconductor industry. Chapter 6 then backtracks to the years immediately following the transistor's arrival, Chapter 7 covers the space age, and the digital era, heralded by the arrival of the microprocessor and family, is described in Chapter 8.

Recognizing that history is made by people and is not just a dry record of events and dates, we've included a gallery of "Great Innovators," profiles of men who have made significant contributions to electronics. A remarkable vitality pervades the interviews they gave our editors. As another historic aside, we have assembled a collection of "Classic Circuits," those that in the view of our editors were turning points in the development of electronic systems. We've even chronicled the chroniclers of these people and events in "A living record of a technology," a history of the magazine itself.

The remainder of the special issue is given over to a forecast of the future—an especially risky business in the case of electronics. Such predictions tend to be a linear projection of the past, but our historical section reveals that technological discoveries tend to elevate the terms of the algorithm of history to higher and often exponential powers. Still, we elected to take the risk and chose the year 2000 as an approachable horizon. Then, with the help of knowledgeable people who are reputable trend-spotters and planners in their own right, as well as much reading and heated discussion among ourselves, we

produced a four-part prognosis for the future.

The first part focuses on the electronic systems and applications of the next two decades and their impact on the home, the workplace, and our lives. The second part examines the changing semiconductor technology underlying these systems, its ever-higher component densities and faster speeds and the trend toward more and more use of digital techniques. How these changes will affect our readers professionally in the next 20 years is examined in the third part. Finally, in the fourth part, we discuss how the electronics industries could be structured by the year 2000.

This volume is the product of the efforts of many people, from editors, who responded magnificently to this mammoth assignment, to the supporting staff of copy editors, editorial assistants and secretaries, who cheerfully accepted the burdens imposed by this issue above and beyond their normally heavy workload. Special recognition is due to Assistant Managing Editor Margaret Eastman without whose unflagging energy the results would have been far less than they turned out to be; Art Director Fred Sklenar and his staff for their highly creative response to the demands of designing this special issue; consultant Richard Haitch, who integrated the huge mass of inputs from our editors into a smoothly flowing historical narrative; and photo editor Yvonne Freund, who relentlessly tracked down and acquired the many interesting and often rare illustrations that grace the pages of the history.

Our gratitude is also extended to the many companies, universities, and other institutions who generously opened their archives and made historic material available to us. Special thanks are also due to Paul Reiss, publisher of *Electronics*, and Dan McMillan, group vice president, for their enthusiastic support of the project, and to Kemp Anderson, my predecessor, who helped establish the standards that guided our efforts.

And finally, we wish to thank you, the readers of *Electronics*, for the support and interest that have sustained us for 50 years. The achievements chronicled here are your achievements. We pledge to continue to serve you in the spirit of the charter established by O. H. Caldwell and his editors 50 years ago. This special issue is our gift to you.

Samuel Weber
Editor-in-Chief

Anniversary portrait. At home in the McGraw-Hill headquarters building are the New York management and editorial staff of *Electronics*.

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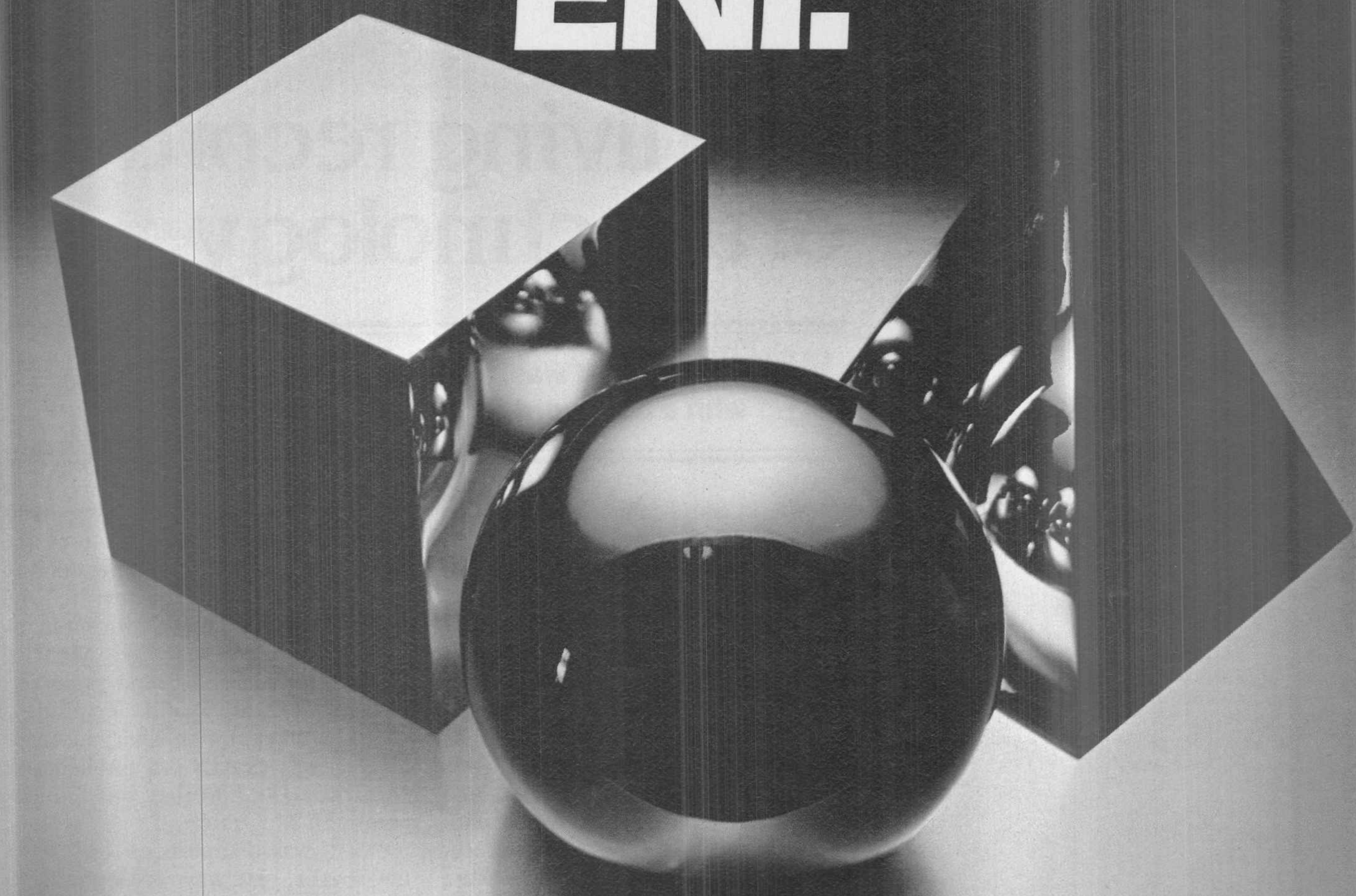

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50 YEARS Electronics

The living record of a technology

There it was, a brand-new magazine with a new word for a name: *Electronics* . . .

. . . what could that mean? The editors made no secret of it, for right underneath the title ran a legend, "Electron tubes—their radio, audio, visio and industrial applications."

Listed in tiny type down the left side of that first cover were 28 applications, some as specific as "musical instruments" and some as general as "measurements." Yes, "radio" was there, along with "television" and "telephony," but then so were "photo-electric cells." The manifold applications of computing power were absent, but who in April, 1930, was thinking about them?

Over the years, the legend has grown up that the founders minted the word, and indeed "electronics" did not appear in dictionaries until many years after the launching of the magazine. However, the word did exist—someone ran across it in a contemporary British publication and plucked it from obscurity to serve as the name. Safe to say, then, that *Electronics* was the making of "electronics."

One of the two associate editors in the magazine's infant years was Keith Henney, who looks back fondly on that period from his retirement home in Snowville, N. H. "Although I was hired to be one of the editors and although I got out the first issue, I was not in on the invention of the paper and had no part in persuading the company to initiate it," he recalls. "*Electronics* was invented by Orestes H. Caldwell and Maurice Clements, then editor and manager, respectively, of Radio Retailing." Manager meant publisher; in those days there was only one publisher at McGraw-Hill, and that was founder James H. McGraw.

"OHC was a superb editor," Henney recalls. "He was very valuable in that he saw broadly . . . . *Electronics* under Caldwell was always way ahead of the procession."

At $3 for 12 monthly issues, the magazine attracted 4,366 paid subscribers during its first year. A glance at early issues makes one thing clear immediately: it was very different from today. The difference lay not just in the subject matter (concentrating heavily on radio, of course), but even more in the type of coverage given to the subject matter. *Electronics* for many years was much like the learned journal of a scientific society. Oh, there were news and new product sections and ample use of photographs showing actual applications, but at the heart of each issue were articles like "An analysis

of efficient modulation," and "The sun's effect on radio," to pick a couple from the 1934 bound volume of issues.

"I wanted a highly technical magazine," Henney recalls. "I wanted to put into writing the things I would talk about at conventions, at Hazeltine, at Bell Labs . . . . I wanted the kind of magazine that these fellows would respect, read, and write for."

The community of engineers was considerably smaller then, so the tiny editorial staff could cover the field. "The things that interested me would interest the guys I talked to," says Henney. "Of course, there weren't nearly as many of them then. I figure about 25 good friends like Harold Wheeler [see the Great Innovators section] and Major Armstrong [developer of the superheterodyne radio receiver and of fm transmission] and that's all I needed."

In retrospect, the tight community of interests may have been the principal factor in keeping the magazine going. It never lost more than a few thousand dollars a year, and it turned slightly profitable well before the end of the Depression, but it was a bare-bones operation. Henney recalls that for a year or so he was the only person putting out the editorial matter—without even a secretary.

He was the linchpin of the magazine, but clearly that could not last forever. The September 1934 issue carries him as managing editor and adds a new name: Donald G. Fink. "I wanted a man who could take my job away from me," Henney says. "He was a lifesaver—had just what we needed: solid technical background, good administrative ability, good news sense, could write." Fink eventually got his boss's job and, to anticipate a bit, went on to a distinguished career in research and at the Institute of Electrical and Electronics Engineers.

The September 1934 issue also carried a lead editorial, "The new day of visual transmission," which included facsimile, as well as television. Forty-five years later, it is difficult to establish a link between that editorial and Fink's arrival. But certainly it is safe to say that the new editorial employee pioneered the coverage of television.

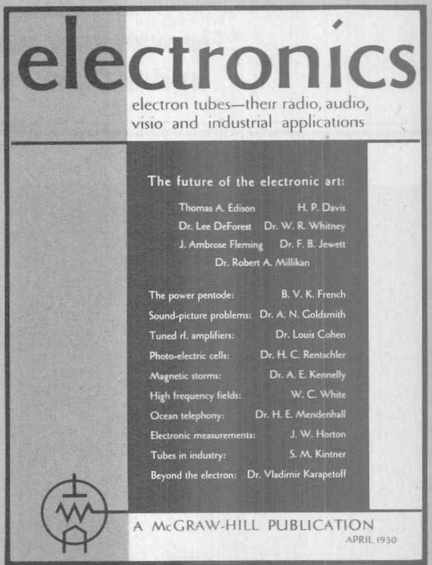
"Caldwell told me he thought I ought to select a specialty that had a potential for growth," Fink says. "I selected TV." He plunged in, visiting RCA Laboratories, Hazeltine Corp., and the few other labs researching TV. He even set up his own lab, at the very top of the old McGraw-Hill Building on West 42nd Street in Manhattan, and there he "produced the first TV set described in print," in a six-part series beginning in the July 1936 issue.

The receiver had a 9-inch, round, green-phosphor cathode-ray tube, with certain key parts coming from RCA Laboratories. A couple of years later, Fink's lab produced a smaller version, described in the magazine as a home receiver. He also began work on a landmark textbook, "Principles of Television," published in 1940 by McGraw-Hill.

By the late 1930s, *Electronics* had begun to grow. Henney dates the growth from the rise in subscription rates from $3 to $5, about the same time he took over as editor, with the September 1935 issue.

The corporation executive vice president, Howard Erlich, was looking for ways to make the magazine profitable, and he proposed to hike the subscription rate. "He thought that half of our circulation at that time [about 6,500 subscribers] would represent the hard core of all the [electronics] purchasing and buying power in the country," Henney recalls.

"I made a deal with him. If he would give me $1 of the extra $2, I would plow it back into the editorial content. We got an art director, used


electronics
electron tubes—their radio, audio, visio and industrial applications

The future of the electronic art:
Thomas A. Edison — H. P. Davis
Dr. Lee DeForest — Dr. W. R. Whitney
J. Ambrose Fleming — Dr. F. B. Jewett
Dr. Robert A. Millikan

The power pentode: B. V. K. French
Sound-picture problems: Dr. A. N. Goldsmith
Tuned r.f. amplifiers: Dr. Louis Cohen
Photo-electric cells: Dr. H. C. Rentschler
Magnetic storms: Dr. A. E. Kennelly
High frequency fields: W. C. White
Ocean telephony: Dr. H. E. Mendenhall
Electronic measurements: J. W. Horton
Tubes in industry: S. M. Kintner
Beyond the electron: Dr. Vladimir Karapetoff

A McGRAW-HILL PUBLICATION
APRIL 1930

April 1930

"Other than the Proceedings of the IRE, it was the only magazine that attempted to deal with complex electronic matters."

"He was very valuable in that he saw broadly . . . *Electronics* under Caldwell was always way ahead of the procession."

Keith Henney

better paper, dressed the thing up, and expanded the content. We put on a circulation campaign. Instead of losing readers, the circulation began to grow, and with a bigger audience, it was easier to sell advertising," he says.

Moreover, the magazine was achieving renown for its coverage of technical matters, certainly a factor in the circulation growth. "It always had a pretty solid reputation," Don Fink maintains. "Other than the Proceedings of the IRE [the Institute of Radio Engineers], it was the only magazine that attempted to deal with complex electronic matters . . . Armstrong said all along *Electronics* was the only magazine that always got it right on his development of wideband fm."

All too soon the war years loomed, changing the face of the world, of electronics, and of *Electronics*. The January 1943 issue gives an idea of the changes. Along with articles like "Electron microscope in chemistry" (by Vladimir K. Zworykin—see the Great Innovators section), there were such features as "Checking resistance welding controls" with CRTs and "Wartime developments in carrier current communication." Also appearing were articles like "Plant procedure for expediting war production."

Henney was putting out the magazine with four editors and an art director. Two more editors were on the masthead, but they were listed "on leave," doing war duty.

One of the two was Fink, who was head of the loran division of the Radiation Laboratory of the Massachusetts Institute of Technology. He went on to become an expert consultant on loran for the Secretary of War, then returned to the magazine.

"When I first got back from the war, of course, I had access to just about everything that had happened at the Radiation Lab," he says. "It was all rapidly declassified and there were a great many great radars that were ready to be described in *Electronics*." The result was an extraordinary series of articles, written by Fink. Of these, Henney recalls: "We got some extra paper, started a series called a war report, and Don began to reveal wartime stuff. I believe the first article was the radar equation. It was a wonderful series."

By now Henney had been shepherding the magazine through its inevitable monthly crises for 16 years, and he was ready for something new. On Nov. 1, 1946, Fink became editor, and his former boss assumed a kind of supervisory editorship, as well as launching a new magazine called *Nucleonics* (which lived into the 1960s) and playing a key role in the Technical Writing division of the McGraw-Hill Book Co. He was no stranger to books, since he had begun writing them in the 1920s. Eventually his list totaled eight, including two on photography that had led to Photo-Technique, a sister magazine that the *Electronics* staff put out for a couple of years just before World War II.

Fink remembers his editorship as a period of expansion, sparked by the growth in the industries the magazine was covering. "Right after the war, electronics was booming in a way that no one could stop," he says. "Consumer electronics was booming; TV was new. Also, there was all that technology—microwaves, superhigh frequencies, magnetrons, solid state (diodes, not transistors)—that was developed during the war and now was available for consumer and industrial use."

In the latter part of Fink's tenure, the magazine took the first steps down what was to prove a sometimes painful road of evolution. "In 1951–52, we felt great pressure from top management to become a magazine more like Business Week," he says. It had gone on from its birth in the depression to scale the heights of general-purpose business coverage. Similar news about the industries covered by the technical magazines would benefit their readers, corporate management reasoned.

Inclined as he was towards tech-

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that had a potential for growth," Fink says. "I selected TV" and "produced the first TV set described in print."

nological development, Fink joined Philco Corp. in mid-1952 as a director of consumer electronics research, eventually becoming vice president of research. On Jan. 1, 1963, he became the first executive director and general manager of the newly formed Institute of Electrical and Electronics Engineers, remaining there until his retirement. Somehow he also managed to find time to write 14 books, and even now he is working on new editions of "Standard Handbook for Electrical Engineers" and "Electronics Engineers' Handbook," both McGraw-Hill publications.

His successor was W. W. McDonald, who started on the corporation's electrical magazines in the 1920s and joined *Electronics* in 1942. Looking back from retirement in Florida, he says his early years on the magazine were devoted to expanding the technical coverage to areas other than radio and communications, where Henney and Fink concentrated. "That I needed a ballpark of my own was a lucky accident," he says, for the magazine needed to expand its coverage as much as he needed his own bailiwick.

As editor, McDonald presided over special issues dealing with subjects like electronics in Europe and microcircuitry. Eventually, of course, coverage of these areas was to become a staple in the magazine's editorial diet.

He also presided over a series of changes in editorial format, as *Electronics* struggled to provide news of the business along with technology news. It all began in December 1956, with what a then ad salesman and later publisher, Dan McMillan, calls "the only trimonthly magazine in the world." Around the first of the month, readers received the engineering edition; around the 10th and 20th they received the business edition. The trimonthly lasted for just over a year, then became a weekly with alternating engineering and business editions, finally becoming a weekly magazine with both kinds of coverage in early 1959.

Resolution of the struggle came in 1964, when Lewis H. Young took over as editor. The magazine was set to go biweekly, since the readers (and the editors) found a weekly *Electronics* too much to digest. Then the Business Week bureau manager in Detroit, Young came on board after extensive discussions with the new publisher, C. C. "Jim" Randolph, and so he knew what changes he wanted.

"We wanted to take the magazine back to what it was: a technical magazine aimed at engineers," he says. "At the same time, we broadened this coverage to include some of the nontechnical elements that impinge on engineering." Of course, a key nontechnical element is business considerations and so the magazine continued to provide that coverage. What was new was the integration of business and technology, notably in the news stories, but also in the technical articles.

The new format bowed with the March 23 issue, timed to coincide with the IEEE International Convention in New York (now the Electro show). "We wanted it out for the show; we could explain it in person to the readers and advertisers," Young says. No need to describe the format: it continues to this day. Also unchanged is partitioning technical coverage by specialties and assigning individual editors to follow them.

Donald G. Fink

Sometime during Young's tenure at *Electronics*, the title of the job was changed to editor-in-chief. He left the magazine with the Jan. 8, 1968, issue to become managing editor and then editor-in-chief of Business Week, later adding to that the title of vice president of the McGraw-Hill Publications Co., which is the magazine operation of the corporation. He left a legacy that is more than a format, for his changes sparked the coverage of the electronics industries as creators and exploiters of technology. Such a view is, of course, rooted in events, for the solid-state revolution was just beginning to be felt.

Young's successor was Donald

Henney recalls: "We got some extra paper, started a series called a war report, and Don began to reveal wartime stuff. I believe the first article was the radar equation. It was a wonderful series."

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Lewis H. Young

Christiansen, the associate managing editor of the technical section and now the editor of the IEEE Spectrum. In recent years, in fact, *Electronics* has served as a spawning ground for editors of a number of other publications.

About the time Christiansen left, a new triumvirate formed to lead the magazine through the 1970s. It consisted of Kemp Anderson as editor-in-chief, Samuel Weber as executive editor, and Dan McMillan as publisher. Their first issue together was June 8, 1970.

The new team could boast of a wide range of experience. Anderson had been a member of the publication company's World News operation and was head of the *Electronics* news operation under Lew Young. Weber had been a practicing electrical engineer for 10 years before first joining the magazine in 1958, eventually becoming the head technical editor. Also, both men had held executive-level jobs in the publications company. McMillan had spent 1961–69 in executive jobs in the electronics manufacturing field at TRW Inc.

Anderson looks back at his stewardship as a period of consolidation. For example, the bureau system of locating reporters in regions that are centers of electronics technological advance was expanded and refined, with particular attention being paid to international coverage. "We continued to pay more attention to international news, and it became more significant as overseas caught up with the U. S.," he says.

Also important was the honing of the concept of the special report. The magazine had for many years pursued an occasional topic in depth, but the 1970s saw a commitment to a continuing process of in-depth coverage. For Sam Weber, an important event was the Oct. 25, 1973, issue devoted to "The Great Takeover." "At that time, we perceived that the pervasiveness of electronics was growing and affecting everyday life beyond belief," he says.

The issue was a success and spawned the annual Technology Update issue. Meanwhile the idea of the special report came into full bloom. "In a long special report, you can emphasize a subject by pulling all the material together," says Anderson. "Also, you can start touching more bases than before: information that was not in earlier stories you now have room for. It is a way of keeping people up to date in a fast developing field and relating that to other developments." Some of the special reports turned out to be prize winners, a notable example being "The Gathering Wave of Japanese Technology" in the June 9, 1977, issue. It garnered one of the prestigious annual Neal Awards for outstanding journalism from the American Business Press association. In the 25 years of those awards, the magazine has won three of them and received three certificates of merit, most of these awards within the last five years.

With *Electronics* poised to enter the 1980s, some important changes took place at the helm. Anderson moved on to become vice president for business systems development for the publications company, and Sam Weber succeeded him as editor-in-chief effective with the Sept. 13, 1979, issue. McMillan had already been promoted to group vice president, which gives him overall responsibility for several McGraw-Hill magazines in addition to *Electronics*. His successor is Paul W. Reiss, who moved up from the position of advertising sales manager.

The magazine is entering its 51st year with an editorial staff of more than 40 men and women, a circulation of about 96,000 including 24,000 overseas, and an international reputation for providing significant news and technical articles. The new team looks forward to a long, productive life.

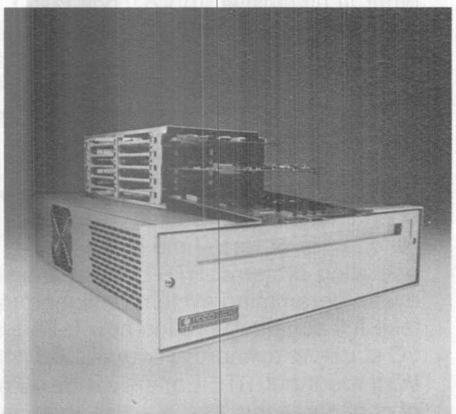
"Electronics is probably the most significant technology to be applied to problem solving for the next 100 years," Weber says. "The increasing recognition of its importance as a mainstay of technological society makes *Electronics*' role more important than ever." □

"At that time, we perceived that the pervasiveness of electronics was growing and affecting everyday life beyond belief."

MEASUREMENT COMPUTATION news

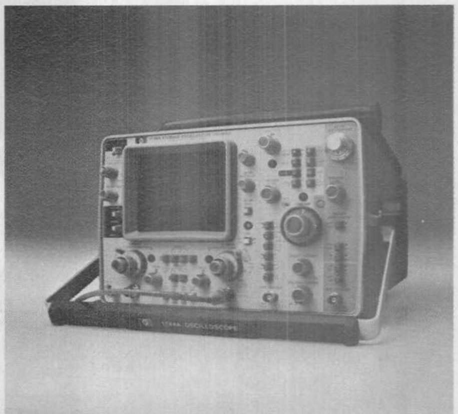
product advances from Hewlett-Packard

INTERNATIONAL edition APRIL 1980

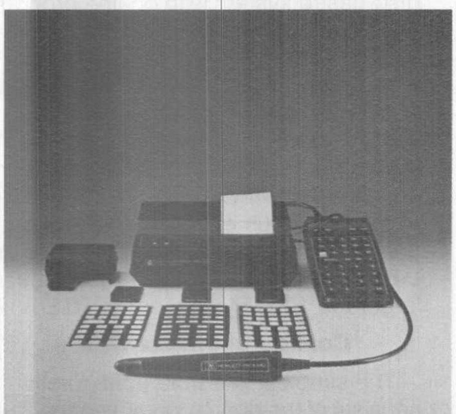


Computers

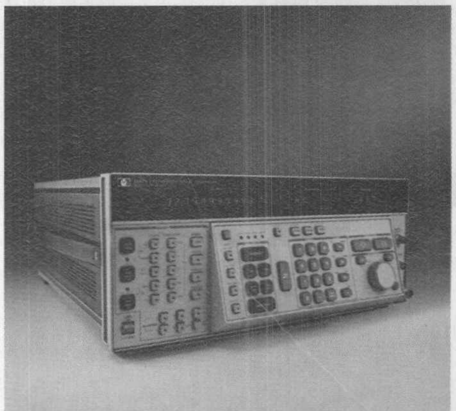
Analyzers



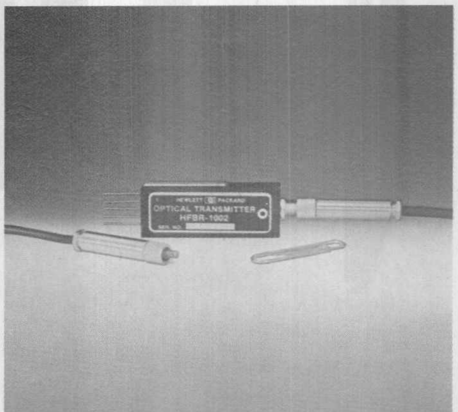
Oscilloscopes



Calculators



Signal Generators



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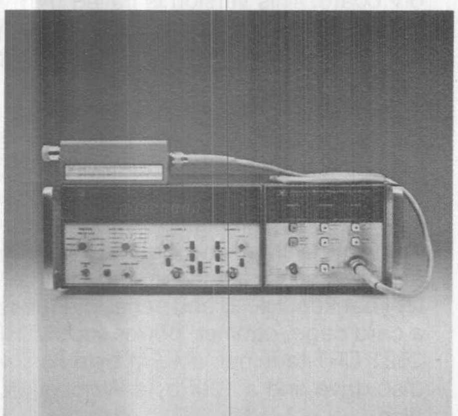
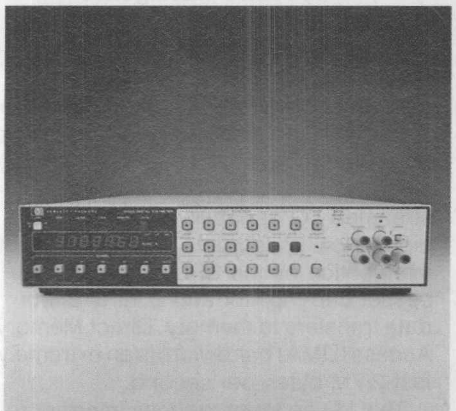


Counters



Voltmeters

Test and Measurement Controllers

Hewlett-Packard—a responsible source for reliable products, systems and services to meet your measurement and computation needs—worldwide.

A new, low-cost HP 1000 computer dramatically improves I/O performance and throughput

The HP 1000 L-Series is a new, low-cost addition to the Hewlett-Packard family of real-time computers. The L-Series puts two advanced processors to work in one computer to create a "Distributed Intelligence" architecture with exceptional I/O speed and flexibility.

The two processors teamed within the L-Series are the result of HP's proprietary CMOS/SOS (Silicon-on-Sapphire) Large Scale Integration manufacturing process, which offers the benefits of very high circuit densities, high speed and low power consumption. One of these custom SOS circuits serves as the L-Series central processor. The other SOS processor is used on every interface board, where it autonomously handles the computer's I/O traffic.

Distributed Intelligence

Because the CPU is relieved of the need to control I/O operations, the "inboard" central processor can concentrate on its main role of computation. The "outboard" processors on each interface board each have full access to memory along with the CPU. The resulting multistreamed I/O capability allows multiple high or low-speed data transfers without intervention by the CPU. Each I/O processor can monitor and control direct data transfers to memory. Direct Memory Access (DMA) bandwidth is an extremely fast 2.7M bytes per second.

This I/O concept reduces interrupt response times, reduces CPU overhead and simplifies the design of interfaces. As a result, an HP 1000 L-Series—available in board, box and system configurations—can perform instrumentation and other I/O-intensive applications faster than computers costing up to five times as much. A wide selection of I/O boards, including an HP-IB interface to many HP instruments and peripherals, is available.

Software

Software for the new L-Series is based upon RTE-L, a compatible member of HP's family of Real-Time Executive operating systems. RTE-L is a real-time multiprogramming system designed to take full advantage of the new L-Series I/O structure to improve overall CPU and I/O throughput. RTE-L offers a wide range of configurations, from a small, memory-based, execute only system to a full disc-based system with on-line program development. RTE-L can supervise execution of multiple, priority-ordered functions in its real-time foreground area while less time-critical operations can share its swappable background processing area. RTE-L supports program development in FORTRAN IV, BASIC and Assembler, plus execution of PASCAL programs. Program development for the L-Series also can be performed on a larger HP 1000 system under RTE-IV.

Configurations for OEM's

The simplest possible configuration consists of the board containing the CPU and its support circuitry, and a 64K memory board. This version is called the 2103LK. OEM's can add a power supply, a 5- or 10-slot card cage and any desired interface boards. $2,250.

Another configuration, a rack-mountable computer, the 2103L, comes complete with processor, memory board, power supply, and 8 I/O slots. $4,450.

The L-Series is also available as a complete system. This Model 10 includes the processor, memory board with battery backup, HP-IB and serial interfaces, a card cage, cabinet, power supply, HP 2621 CRT terminal, a 1.2M byte flexible disc drive and a 12M byte Winchester disc.

Check **B** *on the HP Reply Card for more information.*

HP-IB

Designing your instrumentation system or expanding an existing one? A new HP-IB brochure is now available which describes HP's complete selection of "Designed For Systems" instruments and computers.

This 16-page brochure, *Do Your Own System Design in Weeks, Instead of Months* explains how HP's 10 years of experience building HP-IB instruments and computers for automatic test systems can save you time and energy in your own design.

How can HP-IB products from Hewlett-Packard accomplish this? They can because HP-IB means much more than simply HP's implementation of the IEEE-488. HP-IB represents an integration of features developed and refined over 10 years of experience. These "Designed For Systems" features include:

- a wide selection of measurement system components
- a quick, easy, internationally standardized interfacing scheme
- a large base of documentation and software support
- a variety of customer training courses
- on-site service

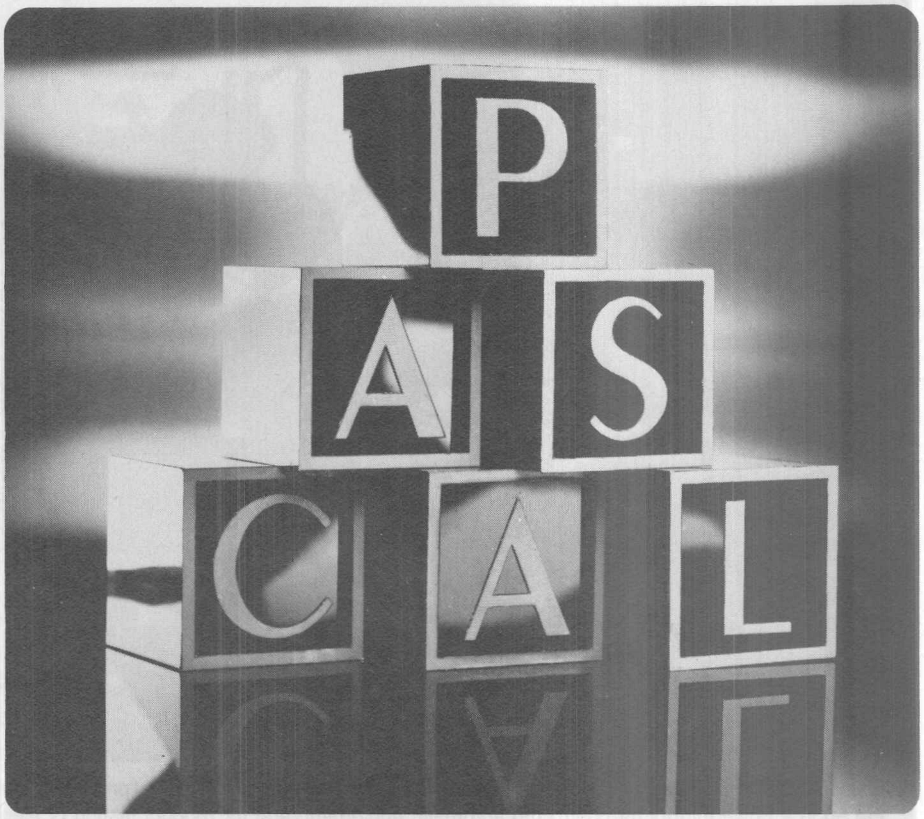
The remainder of the brochure is a very complete and comprehensive overview of the more than 119 "Designed For Systems" Hewlett-Packard instruments and computers. Special information on HP-IB product documentation, software, training, and service support is also provided.

For your complimentary copy of this HP-IB brochure, check **C** *on the HP Reply Card.*

DESIGNED FOR
HP-IB
SYSTEMS

Not just IEEE-488, but the hardware, documentation and support that delivers the shortest path to a measurement system.

HP 1000 computers



A conversational language logically organized in program "blocks," Pascal is easy to learn and easy to follow.

Pascal/1000, Hewlett-Packard's new block-structured programming language for HP 1000 computers, helps improve program design, simplify program maintenance, and reduce overall software costs. Pascal/1000 fully implements the "standard" language defined by Niklaus Wirth, but we've also added several important extensions to enhance Pascal in the HP 1000 programming environment. Furthermore, Pascal/1000 is compatible with other HP 1000 software subsystems—IMAGE/1000, DATACAP/1000, GRAPHICS/1000, and DS/1000.

Technical Applications

Pascal's powerful data structuring and statement control constructs make the language well suited for technical applications. Its general-purpose structure fits non-technical usage as well, and its record-handling capabilities are comparable to those found in COBOL. The addition of Pascal gives programmers greater flexibility in choosing the language most appropriate and efficient for a given project. Moreover, Pascal's readability is invaluable when the program must be maintained later by someone other than the author.

Program Development

For Pascal program development, an HP 1000 system with at least 384K bytes of memory and RTE-IVB operating system is required. The Pascal/1000 compiler translates Pascal source code to assembly language source code, which is then automatically assembled to produce object code. Extensive error-checking is performed during compilation and (optionally) during execution, thus increasing program reliability. In keeping with HP's philosophy of compatible instruction sets, Pascal/1000 object code will execute on any HP 1000 computer.

Right-to-copy licenses, software support, and user training are available. HP order number 92832A includes three Pascal/1000 programming manuals and the Pascal/1000 compiler, library, error message file and cross reference generator on a choice of mini-cartridges, 800 bpi magnetic tape, or 1600 bpi magnetic tape.

For additional details, check **D** *on the HP Reply Card.*

electromechanical testing

This combination of a desktop computer and a versatile measurement and control processor makes the 9030 a powerful tool for controlling automatic equipment, and for product testing of electromechanical devices.

Hewlett-Packard's newest addition to its family of test, measurement and control systems takes the concept of intelligent instrument control one step further by combining a powerful desktop computer with a versatile measurement and control processor. This fully integrated package, designated the HP 9030, offers computer-independent task execution of analog and digital inputs and outputs, HP-supplied System Integration Software, programming simplicity and an HP-IB interface—all in an easy-to-use, roll-around cabinet.

The 9030 consists of an HP System 35, System 45 or 9825S Desktop Computer atop a special instrumentation cabinet containing an extended performance version of the HP 2240A Measurement and Control Processor.

Whether your task is instrumentation interaction, control operations, system debugging, lab development or product design simulation, the 9030 is flexible enough to meet most demanding requirements. This flexibility comes from assigning the computational tasks to the 9030's Desktop Computer while the burden of the control tasks is off-loaded to the separate control subsystem located in the console.

Added Flexibility

The heart of the control subsystem is the HP 2240A Measurement and Control Processor. A state-of-the-art SOS (silicon-on-sapphire) microprocessor gives the 2240A its own intelligence to perform tasks independent of the desktop computer. An HP-IB interface cable connects the control subsystem to the desktop computer. A major advantage of this type of connection is that it allows the desktop computer to control a wide selection of other HP-IB instruments and peripherals.

In addition to independently performing normal input/output operations, the 2240A can also:

- continuously gather large amounts of high-speed data with a single, programmed REQUEST,
- gather historical data leading up to and following a critical event,
- provide a built-in decision making capability based on digital input status,
- perform equipment shut-down upon an alarm condition,
- allow REPEAT/NEXT logic to be nested for subsystem programming convenience and efficiency,
- interrupt the desktop computer upon completion of tasks or upon detection of an error to a measurement.

Minimized Development

With the 9030 you can reduce development time by interacting with the control subsystem through an HP desktop computer. The HP System 35 (9835A) is designed for highly-interactive, single-user applications. Its raster scan CRT, typewriter-like ASCII keyboard, versatile program debugging tools and HP Enhanced BASIC language help you get your system up and running quickly. It also offers:

- 12 digit floating point precision,
- APL-like matrix commands,
- flexible, string variable manipulations,
- high level I/O drivers,
- 50K bytes of user-available r/w memory (expandable to 246K).

If you choose HP's System 45 (9845T) as your desktop computer you get all the features of the System 35, plus full graphic capability (optional) and 187K bytes of r/w memory that is expandable to 449K bytes. Or choose the HP 9825S Desktop Computer. It features an LED line display, built-in thermal strip printer and tape cartridge drive, and 3 I/O ports (expandable to 14). Its high performance capabilities and Direct Memory Access allow the capture of real time data at high speeds.

To find out more about HP's new system, check **E** *on the HP Reply Card.*

HP solves more problems. . .

With a broader range of programmables and more extensive software solutions than anyone else!

With programmable calculators, hardware is only half the story. Having software solutions that work is the other half. Hewlett-Packard's superior software support often means the difference between spending time solving your problems and spending time doing the programming necessary to solve them.

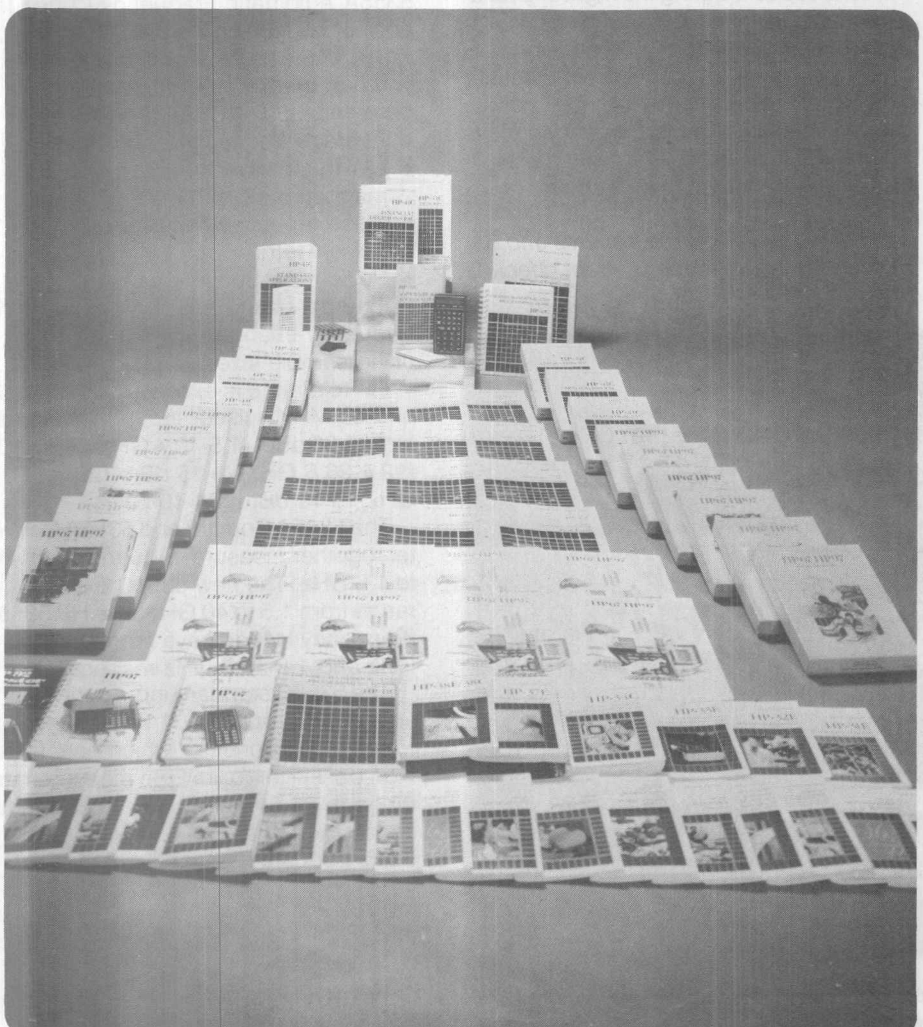
HP's growing library of over 3,500 software solutions covers a wide range of disciplines and applications. From aircraft navigation to x-ray diffraction. And HP software is available in several convenient forms:

- Hundreds of easy to use, step-by-step key-in programs for all Hewlett-Packard programmables
- Preprogrammed magnetic cards for fully programmables
- Plug-in modules
- And soon, bar-coded programs for the HP-41C.

There are also thousands of software solutions in the HP Users' Library. So when you buy a Hewlett-Packard programmable, you're buying a useful, efficient, and complete problem solver.

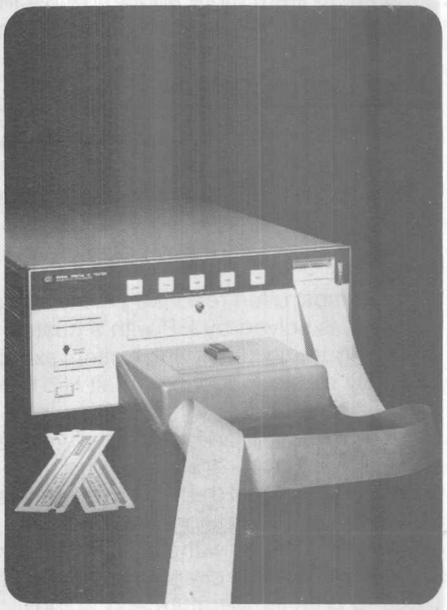
However, the problem it can't solve is deciding which HP programmable is right for you! Hewlett-Packard has eight different scientific and financial programmables to choose from. From the popular HP-33E to the innovative HP-41C—one of them is sure to meet your particular needs. The most extensive range of programmable calculators backed by the most extensive line of software solutions. It's an unbeatable combination.

For prices or more information check **A** *on the HP Reply Card.*



Now over 1900 programs available for IC tester

HP-IB



A simple magnetic programming card makes it a lot easier to learn the truth about the quality of your incoming IC's with HP's 5045A Digital IC Tester.

There's probably no easier way to get fast, accurate screening of your incoming ICs than with HP's 5045A. Set-up is as easy as inserting a magnetic card. You can get as much or as little data as you want. The IC programs you need are almost certain to be in our growing library of over 1900 programs covering today's most used ICs from bipolar to MOS and from gates to RAMs.

Find Out a Little or a Lot

Touch a button and you get immediate pass/fail indication. Need to know more about the failure? Push another button and get a complete printout of the test with the failure point indicated.

Customize Your Test Programs

Want to refine a test procedure? Need a test for a special IC? The HP 5046A Digital IC Test System lets you write your own custom test programs. It includes the HP 9825S Desktop Computer, a powerful computing instrument that you can also use for many other tasks, such as program storage or general-purpose computing. The 5045A also interfaces with a large variety of the major IC handlers.

For further technical data, check **F** *on the HP Reply Card.*

HP's 1700 series oscilloscopes solve 3 common measurement problems

HP recently surveyed the electronics market to learn more about how oscilloscopes are being used and the problems encountered when making measurements. The three most common measurement problems reported by oscilloscope users were triggering, hard to see traces, and displaying fast pulses. HP's 1200 series oscilloscopes solve all three of these problems.

Stable Triggering

The most often reported problem, triggering, is solved by HP with a custom ECL triggering circuit which offers exceptionally stable triggering. In all HP 1700 series oscilloscopes, this proven integrated circuit is independent of vertical position controls—traces can be repositioned without the need to reestablish trigger synchronization. Triggering is more reliable than with the more conventional tunnel diode circuits which can drift due to both temperature and aging.

Bright Traces

The second most reported problem, hard to see traces, is solved by 1741A and 1744A variable persistence storage oscilloscopes. Variable persistence integrates repetitive signals for easy viewing. Practically any signal can be viewed as a sharp, bright trace regardless of repetition rate or speed. And with the auto-intensity feature, both oscilloscopes make it easy to avoid trace blooming over a wide range of beam intensities and sweep speeds.

Fast Writing Speeds

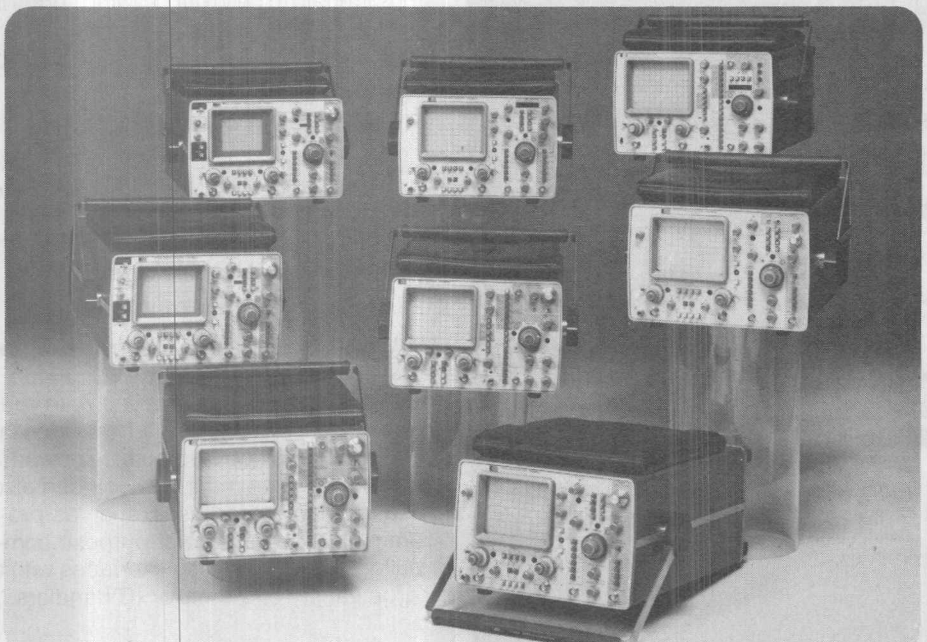
The third problem, display of extremely fast pulses, is solved by the fast writing speeds of HP's storage oscilloscopes—200 cm/μs in the 1741A and 1800 cm/μs in the 1744A. With 1800 cm/μs you can display a single shot, 100 MHz sinewave with an amplitude of eight divisions.

Full writing speed is available in all operating modes—variable persistence, auto-erase, and auto-store—giving you the freedom to select the operating mode that matches your measurement.

Additionally, the 1741A will wait indefinitely in the auto-store mode for a single-shot event to occur. When coupled with the auto camera option, this instrument will operate unattended to provide a permanent trace photograph of an event—even if it occurs during the night or over a weekend.

What's more these 1700 series oscilloscopes have established an excellent record for reliable performance. However, if a failure does occur, easy access to internal components makes these oscillocopes very easy to repair.

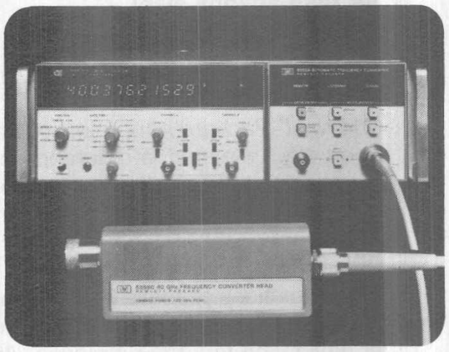
To learn more about the features and benefits offered by these scopes, check **G** *on the HP Reply Card.*



HP's 1700 oscilloscopes can provide the answer to your mesurement needs with 100, 200 and 275 MHz bandwidths, with reliable triggering and operation.

Measure pulsed and CW frequencies up to 40 GHz automatically

HP-IB



With HP's new 40 GHz Universal Microwave Counter package you'll be able to make all the frequency and time interval measurements you're likely to need in microwave applications.

Now you can measure pulsed and CW frequencies automatically and accurately all the way up to 40 GHz. Just add HP's new 5356C Frequency Head to HP's 5355A Automatic Frequency Converter and HP's 5345A Universal Counter. Then, with a single set up, using a single input, you can quickly measure these radar parameters:

- Average frequency in a pulse
- CW microwave frequency (STALO, magnetrons)
- Pulse repetition frequency
- Pulse width
- Pulse repetition interval

External gating enables you to profile frequency changes within the pulse, using sample sizes as brief as 20 ns.

FM tolerance is excellent: 60 MHz CW and 80 MHz pulsed. Input sensitivity is high: −25 dBm (1.5-12.4 GHz), −20 dBm (12.4-26.5 GHz), −15 dBm (26.5-34 GHz), −10 dBm (34-40 GHz).

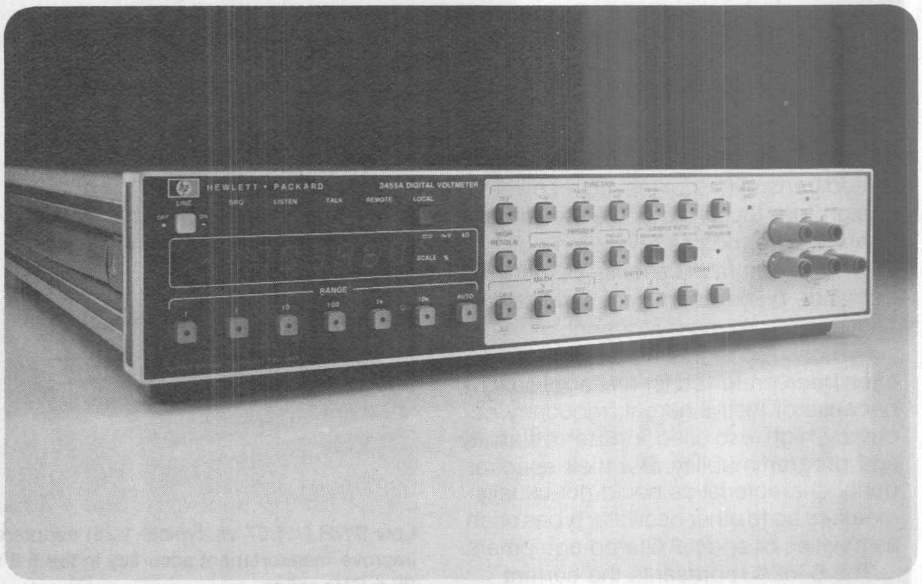
The 5345A Counter and 5355A Converter together measure frequency from DC to 1.6 GHz. The new 5356C extends the range from 1.5 to 40 GHz. The HP 5356A Frequency Heads have ranges of 1.5-18 GHz and 1.5-26.5 GHz respectively.

The 5356C standard input connector is an APC 3.5; option 001 substitutes a waveguide connector which acts as a high pass filter to limit the measurement range to 26.5-40 GHz. For the systems capabilities of the HP-IB, order your 5345A Counter with option 011.

Check **H** *on the HP Reply Card for all the details.*

and calibrates itself

Microprocessor-controlled digital voltmeter checks its dc and ohms circuits for accuracy then makes corrections.



Using two microprocessors, one for measurement control, and the other for computation and remote programming, Hewlett-Packard's fully-guarded, integrating 3455A Digital Multi-Voltmeter is designed for bench or systems use. It measures dc from 1 μV to 1,000 V, true rms ac from 10 μV to 1,000 V, and either two or four wire resistance from 1 mΩ to 15 MΩ. A high-resolution mode uses 6½ digits, but for faster reading, 5½ digits are used.

Using a parallel structure control oriented microprocessor, the HP 3455A has autocalibration which provides high accuracy and a removable reference assembly that greatly simplifies calibration of dc and ohms.

Mathematical functions built into the 3455A let the user offset, take ratios, or to scale readings so that readouts are in physical units. A '% ERROR' mode converts readings into percent change compared to a predetermined reference.

DC measurements are made at 24 readings per second (22 readings per second for 50 Hz) with 1 μV sensitivity. Greater than 60 dB normal mode noise rejection is obtained on all dc ranges. Dc accuracy is ±0.0023% at full scale.

True rms measurements are made to 13 readings per second at frequencies above 300 Hz. True rms is measured with the best accuracy of 0.1% over a 30 Hz to 1 MHz bandwidth. Signals with a crest factor as high as 7:1 full scale can be measured.

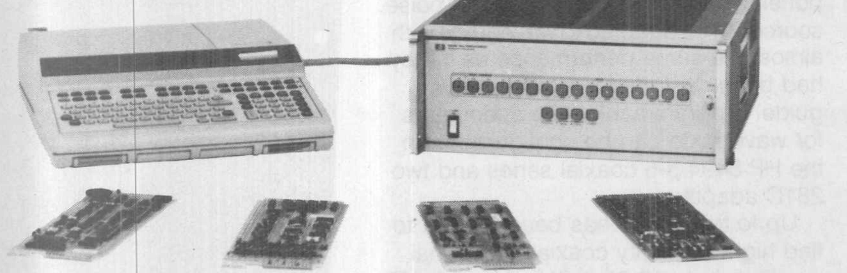
Resistance is measured in six ranges from 100 Ω to 10 MΩ full scale with best accuracy of 0.0025% at full scale.

Maximum current through the unknown is less than 1 mA. Internal circuits are protected against overvoltage.

Standard on the 3455A is an HP-IB I/O for systems operation. The front panel indicators on the 3455A display range, function, and HP-IB status during remote operation.

Check **I** *on the HP Reply Card for full information.*

New high-speed scanner card expands multiprogrammer production test capability



Use HP's 6940B Multiprogrammer with its 32 different plug-in functions for interfacing a desktop computer to the equipment you want to automatically control.

A new HP 69336A High-Speed Scanner Card now permits HP's 6940B Multiprogrammer, to sample 20,000 channels-per-second of voltage input. This enables the multiprogrammer to act as the vital link between an HP desktop computer or minicomputer and your test or control process.

Thousands of 6940B multiprogrammers are now in operation, saving time and money in user defined and assembled systems for production testing and control, data acquisition, and process monitoring. Multiprogrammer hardware includes mainframes and a family of 32 plug-in cards providing specialized stimulus, measurement, control and acquisition functions.

Check **J** *on the HP Reply Card to obtain more information on the 6940B Multiprogrammer and technical data on the 69336A High Speed Scanner Card.*

simulation

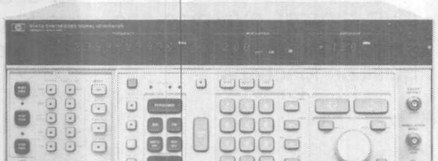
Signal generators are used as calibrated transmitters for testing receivers in design, production, and maintenance phases. With today's revolution going forward in communications systems, the demands placed on signal simulators continue to get more stringent.

Synthesized signal generators have often been preferred for test applications because of their inherent frequency accuracy, high resolution, long term stability and programmability. But their spectral purity characteristics could not usually measure up to other oscillator types such as cavities or special filtered equipment.

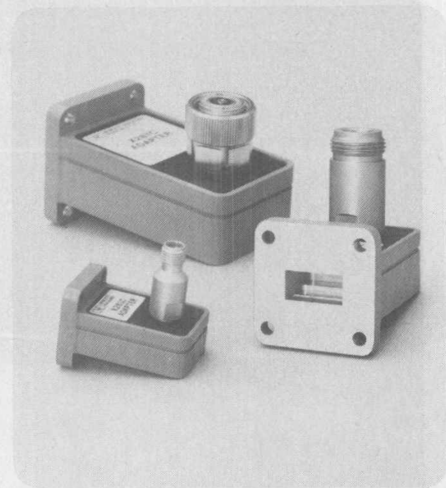
The 8662A represents the current state-of-the-art signal quality performance on SSB phase noise with less than −144 dB/Hz at 10 kHz offset at 160 MHz. Non-harmonic spurious signals are below −100 dBc. It also achieves superior performance on output level accuracy of ±1 dB from +13 to −120 dBm.

As a forerunner of future signal generators it is perhaps even more significant that the front panel design makes use of its internal microprocessor to store and recall nine complete sets of front panel settings, either individually or in a specified sequence. Powerful step-sweep capability with log or linear scan further enlarges the generator capability into applications requiring sweep tests of high stability components. Also, certain frequency agility receivers can be tested because the 8662A switching time is typically less than 12 ms settling time to be within 100 Hz.

*Check **K** on the HP Reply Card for full specifications.*



The SSB phase noise of this 1280 MHz synthesizer rivals the best cavity-type generators



Low SWR (<1.07 vs. typical 1.25) adapters improve measurement accuracy in the 8.2 to 26.5 GHz range.

The utility waveguide/coax adapter used for years by the microwave industry has been typified by the HP 281A. At the band edges, the 281A typically exhibits an SWR of 1.2 and at band center can be as good as 1.08. For system use, such performance was usually satisfactory. But for measurement applications, better SWR is desirable to minimize errors.

The new HP 281C series adapters now meet that need with a stepped taper design concept which delivers very low SWR. Three bands are available:

- X281C, 8.2-12.4 GHz, SWR<1.06;
- P281C, 12.4-18 GHz, SWR<1.06;
- K281C, 18-26.5 GHz, SWR<1.07.

Typical units have SWR about half that value.

This low SWR now allows coaxial components such as power sensors or noise sources to be adapted to waveguide with almost the same performance as if they had been designed directly in waveguide. Programmable step attenuators for waveguide can be configured from the HP 8494-5-6 coaxial series and two 281C adapters.

Up to this time it has been difficult to find high directivity coaxial directional couplers from 18-26.5 GHz. Now an HP K752C waveguide coupler and a K281C adapter can provide an APC-3.5 test port with equivalent directivity of 28 dB.

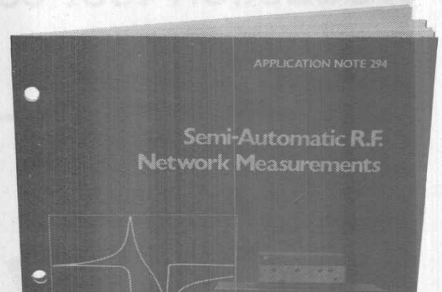
*If you need more details, check **L** on the HP Reply Card.*

extended frequency coverage and new application note

HP's 8754A Network Analyzer, a complete and cost effective stimulus-response test system covering 4 to 1300 MHz, is now also offered in a modified version that will measure to 2600 MHz. This version, designated 8754A Option H26, performs just like the standard unit to 1300 MHz with only nominal loosening of specs clear to 2600 MHz. For example, dynamic range, which is 80 dB to 1300 MHz, is still 72 dB at 2600 MHz. A transmission-reflection test set and precision power splitter with 2600 MHz capability are also available. The price increment between the standard system and the 2600 MHz version is about 15%!

The 8754A Network Analyzer also plays a "starring role" in a new application note that describes how to configure and operate a computer-controlled measurement and data logging system. The system described in AN 294, "Semi-Automatic RF Network Measurements," is especially valuable in applications where many measurements must be made efficiently and where collection of actual measured data is important. Included are programming instructions, sample programs, and modifications needed to make crystal filter measurements.

*Check **M** for information on the 2600 MHz version of the 8754A. Check **N** for a complimentary copy of AN 294.*



HP logic analyzers have measurement solutions for digital dilemmas

Do you want to sort out multiplexed buses, trace real-time execution of complex branches, check out hardware problems tied to software sequences, or find that random glitch that causes your system to crash? Then look at the feature sets of any of HP logic analyzers to find the optimal tools for your digital measurements.

An increasing number of newer microprocessors are using multiplexing. With three clocks (using from one to six edges) and a holding register, HP's 1610B Analyzer can capture related events occurring at different times, and display them as a single, 32-bit line on the analyzer's display. It allows the user to see and trigger on system activity with the address, data, and control lines correlated as one event, rather than appearing as three sequential lines.

HP's 1615A Logic Analyzer not only collects state and timing information simultaneously, but it also offers a variety of trigger modes using both functions. Either function can immediately trigger the other, or one function can arm the second. Of course, the 1615A can also operate as a stand-alone state analyzer or only as a timing analyzer. The HP analyzers solve glitch problems by separating the glitches from other incoming information, storing them separately, and displaying them distinctly. Glitches can be used as trigger parameters, too.

Real-time, transparent monitoring of digital systems with HP logic analyzers lets you pinpoint minor flaws before they become major crises in the design, production, or service of your digital system.

Troubleshooting with Analyzers

Troubleshooting and debugging with logic analyzers are described in Application Note 292, a 16-page booklet, "Minicomputer Analysis Techniques Using Logic Analyzers."

Hewlett-Packard has a complete line of logic analyzers to meet your digital measurement needs.

Check **O** *on the HP Reply Card for literature with more specifics on HP logic analyzers. Check* **P** *for a free copy of Application Note # 292.*

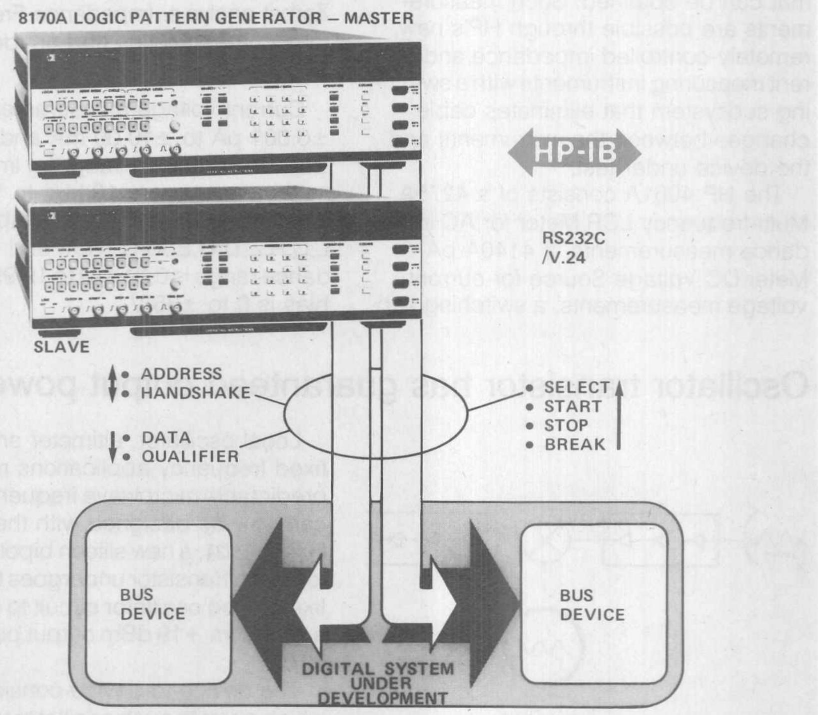
Convenient solution for stimulating wider buses

Your requirement for digital stimulus with up to 32 bits parallel can be solved by master/slaving two HP 8170A Logic Pattern Generators.

Designed for simulating system conditions for a wide range of digital devices, the 8170A generates control signals and address, as well as data. Consequently, devices using latch-, RAM- and handshake-interfaces can be functionally tested independent of the rest of the system.

A new brochure is now available which shows how the bus width capability can be extended by synchronizing the outputs of two 8170A's. In addition to giving timing and operating information, the publication also describes the 8170A-HO2 which offers an additional clock output to improve synchronization of the slave.

For full master/slave details, and 8170A data sheet, check **Q** *on the HP Reply Card.*



With many bus capabilities, the 8170A can stimulate practically any bus device. A single slave 8170A increases the bus width capability to 32 bits.

HEWLETT-PACKARD

Now, measure power to 26.5 GHz in coax

HP-IB

Power measurements to 26.5 GHz can now be made easier and more accurately. Hewlett-Packard's new 8485A Power Sensor covers a frequency range from 50 MHz to 26.5 GHz and a power range from −30 dBm to +20 dBm (1μW to 100mW). A very low SWR specification results from using thermocouple technology (1.25 at 26.5 GHz) which reduces mismatch uncertainty.

CAL FACTOR is plotted at 34 frequencies on the attached label with data traceable to the U.S. National Bureau of Standards. This permits an adjustment on the power meter to compensate for variations of the sensors' efficiency and mismatch loss. For example, RSS uncertainty at 26.5 GHz is ±3.21%. Further correction for mismatch uncertainty can be made using actual measured SWR which is furnished.

The input connector is APC-3.5 to provide rugged and repeatable performance over hundreds of connections. It mates directly with SMA.

The 8485A was designed to be used with HP's 435A and 436A power meters. The 435A Analog Power Meter features one percent instrumentation accuracy. The 436A Digital Power Meter features 0.5 percent instrumentation accuracy and optional programmability through BCD or HP-IB.

*Check **R** on the HP Reply Card for data sheet.*

New test system designed for fast, accurate, automatic semiconductor and electronic component evaluation

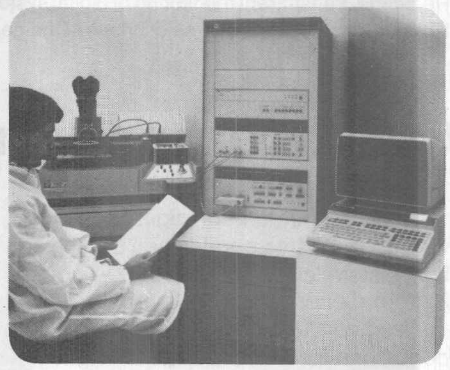
HP-IB

This new Hewlett-Packard 4061A Semiconductor/Component Test System provides reliable and accurate measurements and high speed data processing. Measurement results such as an impurity profile or surface state density of a semiconductor device in any data format can be obtained. Such measurements are possible through HP's new, remotely-controlled impedance and current measuring instruments with a switching subsystem that eliminates cable changes between the instruments and the device under test.

The HP 4061A consists of a 4275A Multi-frequency LCR Meter for AC impedance measurements, a 4140A pA Meter/DC Voltage Source for current-voltage measurements, a switching subsystem, a 9835A desktop computer and a systems library.

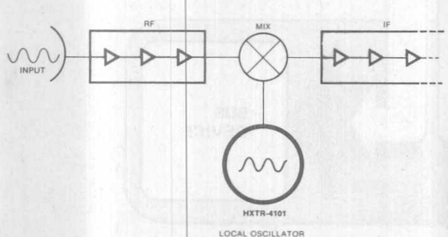
The Systems Library contains manuals, diagnostic programs and includes seven application pacs; semiconductor high/low frequency C-V characteristics, I-V characteristics, C-t characteristics, Zerbst analysis, Impedance Frequency/Bias characteristics and an ideal C-V curve.

Current-voltage measurements are ±0.001 pA to ±10.00 mA and 0 to ±100 V. Frequency range for impedance measurements are 10 kHz to 10 MHz. Eleven parameters are available: L,C,R,Z,D,Q,ESR,G, Θ,X, and B. Impedance range is 0.01 mΩ to 19.99 MΩ. DC bias is 0 to ±35 V.



*Further information can be obtained by checking **S** on the HP Reply Card.*

Oscillator transistor has guaranteed output power



Local oscillator, altimeter and other fixed frequency applications requiring a predictable microwave frequency source can now be designed with the HP HXTR-4101, a new silicon bipolar transistor. Each transistor undergoes testing in a fixed tuned oscillator circuit to guarantee a minimum +19 dBm output power at 4.3 GHz.

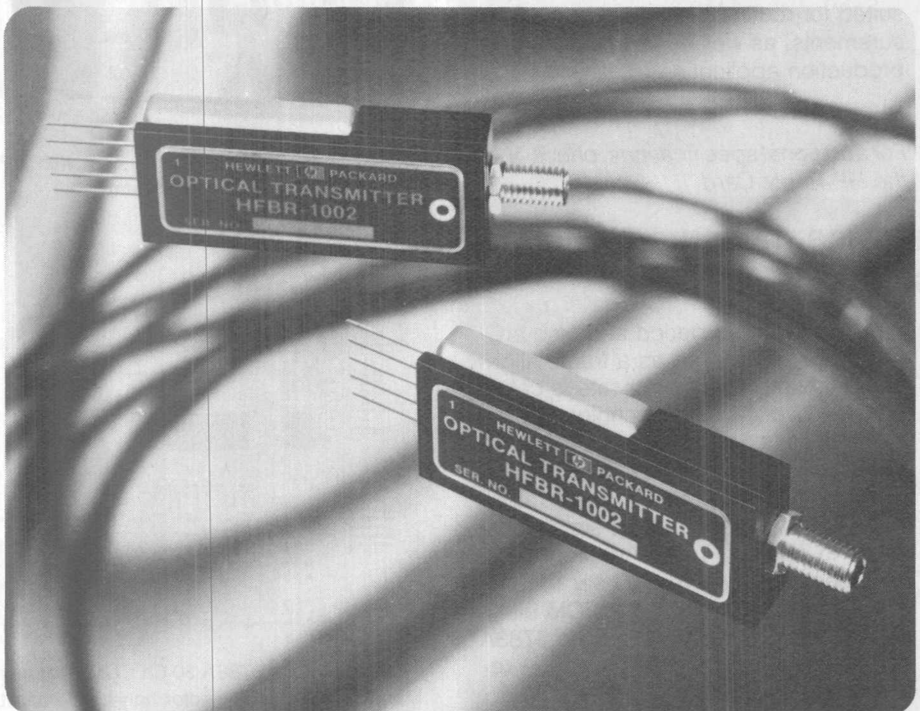
The device-to-device consistency which permits such oscillator testing can be employed in your system over a wide range of frequencies through the use of characterization data available.

With typical output power of 112 mW at 4.3 GHz, 50 mW at 6 GHz, and 15 mW at 8 GHz, this device is an effective selection for applications up to 10 GHz that require a reliable source with low phase noise characteristics.

The HXTR-4101 is hermetically packaged in a 2.5 mm square HPAC-100.

*Check **T** on the HP Reply Card for more information.*

New 1000 metre fiber optic transmitter extends the range of data communication links



Fiber optic systems transmit digital information in the form of light pulses guided by hair-thin optical fibers instead of the traditional electrical signals using copper-based wires. As such, fiber optic systems are neither affected by nor contribute to the surrounding electromagnetic noise in the environment.

The new Hewlett-Packard HFBR-1002 Fiber Optic Digital Transmitter makes it possible to install new fiber optic links or extend the range of existing HP links to 1,000 metres. The transmitter is an integrated electrical-to-optical transducer designed for digital data transmission over single fiber optical cables. A bipolar integrated circuit and a new high-efficiency emitter convert TTL-level inputs to optical pulses at data rates from dc to 10 Mbaud.

Burrus LED

The heart of this new transmitter is a high power, high efficiency GaA1As infrared emitter which makes the longer transmitting distance possible. The new emitter is a Burrus light emitting diode specifically designed by HP for fiber optic applications. The output wavelength of the emitter is 820 nm which matches the optimum spectral transmission of the silica core and clad fibers used in Hewlett-Packard systems. Reliability of the new device has been confirmed by thousands of hours of life testing under both normal and accelerated conditions.

The HFBR-1002, when used with the HFBR-2001 Fiber Optic Receiver and an HFBR-3000 Series Cable/Connector assembly, guarantees system performance at 1,000 metres with at least a 2.6 dB flux margin. The bit error rate at this distance is better than 10^{-9} at the maximum specified data rate of 10 Mbaud.

Extended Range

The new HFBR-1002 transmitter is pin-compatible with the HP HFBR-1001 100-metre transmitter and thus can be used to extend the range of existing systems to 1,000 metres. The HFBR-2001 receiver is designed to work with the HFBR-1002 transmitter at any distance from 1 to 1,000 metres without requiring adjustments. This performance is made possible by the built-in automatic level control of receiver amplifier gain over a 23 dB range.

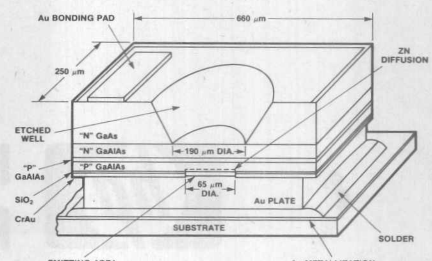
To complement the new transmitter in system installations, HP is now also making available its fiber optic cable/connector assemblies in user-specified lengths. They are available in one metre increments from 1 to 1,000 metres.

Features of Hewlett-Packard fiber optic systems include:

- Specially designed plug-together transmitters, receivers, and cable/connector assemblies
- PC board mountable transmitter and receiver packages
- Standard LSTTL electrical interfaces
- Single +5 V power requirement
- No restriction on input data format from dc to 10 Mbaud
- Special "link monitor" built into receiver to provide warning when information flow is interrupted.

*Check **U** on the HP Reply Card for complete details.*

BURRUS EMITTER STRUCTURE



Microwave link analyzer offers low-cost solution to digital-radio testing

Direct RF modulation radio relay systems are becoming increasingly popular. The testing of these systems does not always require the IF transmitter sections of conventional microwave link analyzers. Hence the new HP 3707A BB + Sweep Generator has been designed to drive an HP 8620C Up Converter to give a swept, frequency-modulated source with a range of 0.5 to 18 GHz. This source, in conjunction with a standard HP 3702B or 3712A IF/BB Receiver, allows the measurement of transmission distortions in a radio link. Although the principal area of application is in digital radio testing, the measurements are equally useful for analog radio systems which use direct modulation.

The 3707A provides a single, low-frequency test tone of 250 or 500 kHz (internally selectable) which allows the measurement of linearity or group delay. The 3702B IF/BB Receiver is suitable for use on systems operating at 70 MHz IF while the 3712A, in addition to 70 MHz IF, provides a capability at 140 MHz IF. Further, an HP 3730A Down Converter, with appropriate RF plug-in, may be used to help isolate distortions in the RF parts of a link.

The new MLA system has been designed with low cost and ease of use as primary considerations and is ideally suited for routine maintenance measurements, as well as installation and production applications.

For additional specifications, check **V** *on the HP Reply Card.*

Measuring a 6 GHz branching filter with HP's new low-cost RF/IF MLA system.

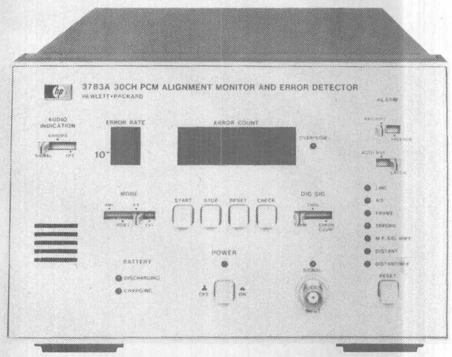
Portable monitor makes in-service measurements on 2 Mb/s PCM/TDM transmission systems

With HP's new, low-cost 3783A 30 Channel PCM Alignment Monitor and Error Detector you can make both in-service and out-of-service measurements on 2048 kb/s digital transmission systems conforming to CCITT Recommendation G.732 (European CEPT 30-channel PCM multiplex standard). The instrument detects and counts Frame Alignment Signal errors and AMI or HDB3 code violation errors.

In accordance with a new CCITT O-series Recommendation relating to PCM frame alignment monitoring and code error detection, the 3783A displays measured results as an error count over a manually selected period and also an error rate. When used as a frame alignment monitor, the bit error rate is calculated using a statistical technique based on the assumption that the overall signal contains a Poisson distribution of errors.

The instrument also incorporates a LED display of the system alarm states contained in TS0 and TS16. An integral loudspeaker allows you to hear the presence of either errors or the PCM bit stream. In external operation, the 3783A counts low frequency TTL pulses. A rechargeable battery option is available.

Check **W** *on the HP Reply Card for details.*



The easy-to-use 3783A 30 Ch PCM Alignment Monitor and Error Detector has a strip chart recorder output to let you make hard copies of the measurement results.

MEASUREMENT COMPUTATION **news**

product advances from Hewlett-Packard

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HEWLETT PACKARD

March/April 1980

New product information from

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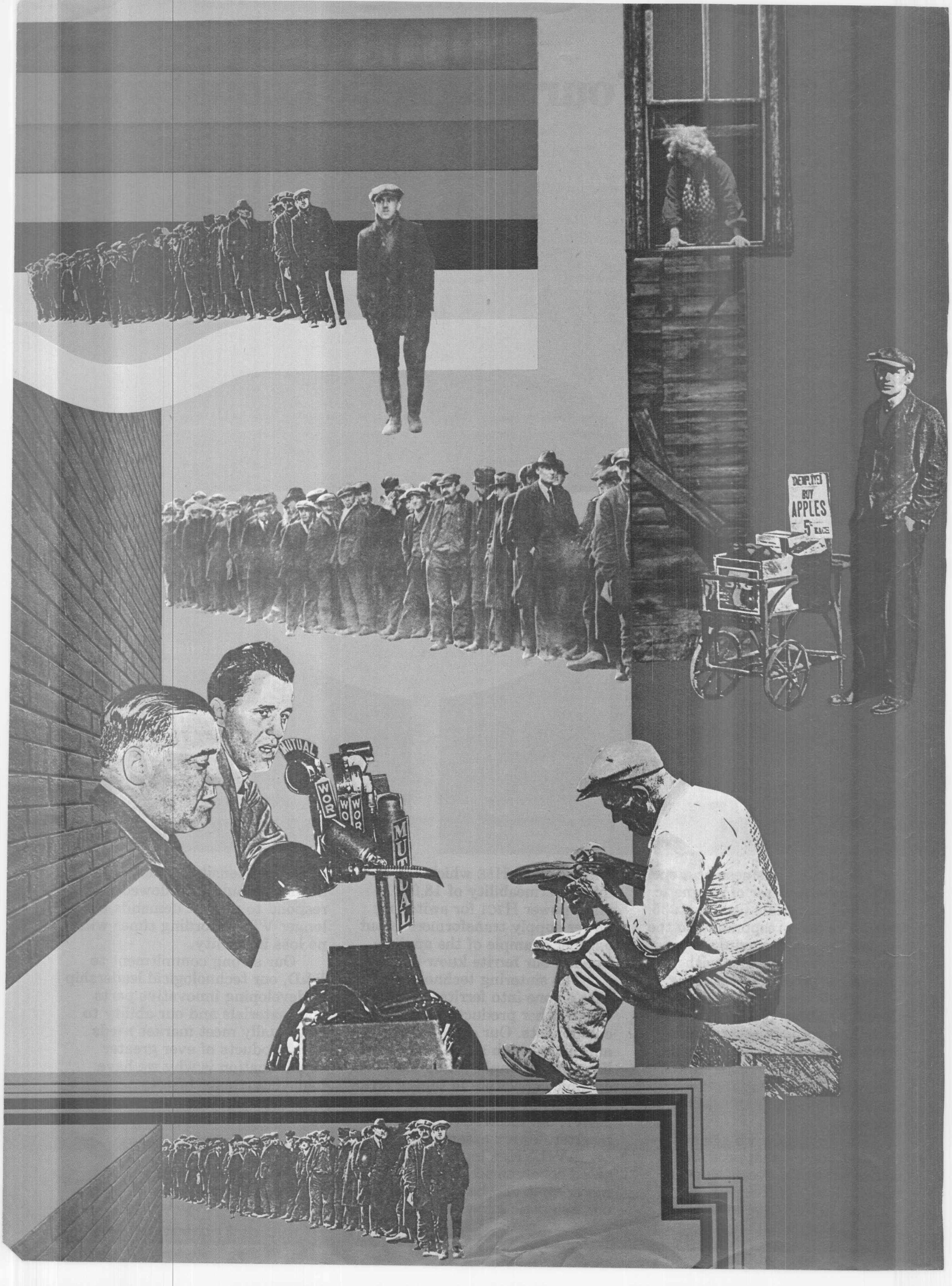
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FIFTY YEARS AGO

1930: AS THE NATION AND THE WORLD BEGAN THE LONG ECONOMIC SLIDE THAT WOULD TERMINATE IN WORLD WAR II, THE ELECTRONICS INDUSTRY—A MAJOR BENEFICIARY OF THAT BLOODY CONFLICT—WAS BUSILY DEVISING SOLUTIONS TO ITS MANY TECHNICAL AND ECONOMIC PROBLEMS. COMMERCIAL BROADCASTING WAS 10 YEARS OLD; IN HIS NEW YORK LABORATORIES, E. HOWARD ARMSTRONG WAS WORKING ON FM; AT RCA'S CAMDEN, N.J., FACILITY, VLADIMIR ZWORYKIN WAS PERFECTING TELEVISION; AND BELL LABS ANNOUNCED THE INVENTION OF NEGATIVE FEEDBACK BY HARRY BLACK AT ITS HEADQUARTERS ON WEST STREET IN NEW YORK.

Chapter 1

It was not a good year. The start of a fresh decade, yes. But fresh hopes, new dreams? Not many.

It was 1930. The nation was still in shock from the shattering of the stock market in the autumn of 1929. Disillusionment infected financial and business circles. And worse was yet to come.

"Business is fundamentally sound" was the rallying cry uttered repeatedly by business and Government leaders. But most businesses were not sound at all. A figure that came to symbolize the Depression in the United States—the apple peddler—was to appear before 1930 was out. The bubble of the Roaring Twenties had burst. Unlimited consumption of unlimited production, all spurred by easy credit, was a frothy myth.

Electronics magazine was launched on this stormy economic sea. Its editors were emboldened by the state of electronic technology to write in the inaugural April 1930 issue:

"Already billion-dollar industries are built upon the vacuum tube—in telephony, in radio, in talking pictures, and in power applications. Electronics revolutionized the first three—made them possible. And in the power field, it is now affording an entirely new engineering approach to electrical problems of every kind. For although the electrical engineering of the past was built almost wholly upon the single principle of electromagnetic induction, the electrical designer of today finds . . . that in electronic apparatus he commands a medium paralleling magnetic-induction in importance and its equal in wide adaptability."

Radio had already become firmly established as an exceptional entertainment medium. The year 1930 marked the 10th anniversary of commercial radio broadcasts from stations in Detroit, San Francisco, Newark, and Pittsburgh. Live broadcasts just the year before from the flight of Comdr. Richard E. Byrd over the South Pole had set the world agog with speculation about what future communications technology might have in store for it.

David L. Sarnoff, president of the then Radio Corp. of America, wrote in that first issue of *Electronics*: "Potentially there are 26 million theatres in this country, awaiting development. Every home can ultimately become a theatre itself."

The electronics that Sarnoff had in mind for his "theatres"—television—had been demonstrated by Bell Telephone Laboratories in 1927. While it was being developed, manufacturers' sales of "radio apparatus and tubes" reached \$353.6 million in 1929, exceptional

Once they built a railroad. Unemployed men on bread lines like this one in front of the fashionable shops on New York's Fifth Avenue were a common sight during the Depression. Radio provided just about all the entertainment millions like them could afford.

growth from the $198.4 million of 1927, according to Moody's Industrial Analysis for 1930. This figure was dwarfed by the "electrical machinery" category, which included telephones, lamps, motors, generators, and household appliances. Moody's set sales for these products in 1929 at $2.33 billion.

Electric power was available in about 20 million of the the 29 million homes in the U. S., and 20.2 million telephones had been installed. An increase of 900,000 phones in 1929 was the largest in any year, according to a report in August 1930 by technical committees of the American Institute of Electrical Engineers. Some 21.5% of the phones were dial, as opposed to those relying on a central operator to place the call. Telephone circuits were also being used to connect chains of radio broadcasting stations.

It was at about this time, too, that airplanes flying at night were first guided by low-frequency directional radio beacons. The Aeronautics Branch of the Department of Commerce, created by the 1926 Air Commerce Act and a forerunner of today's Federal Aviation Administration, installed the first six of these beacons along the high-density routes between New York, Washington, and Chicago. Spaced 25 miles apart along the airway corridors were supplementary 7.5-watt radio marker beacons. Aircraft radiotelephones followed, providing pilots with updated reports of the weather they could expect en route to an airport and at the landing ground itself.

Commercial shortwave radio service had started in 1929 from the U. S. to ships at sea, and in September of that year, at the Hague, there had been the first meeting of the newly organized International Technical Consulting Committee on Radio Communication, or CCIR. Among its goals: international understanding on technical standards for minimizing frequency interference. In the U. S. itself, the recently established Federal Radio Commission was beginning to bring order to domestic broadcasting chaos.

In entertainment, "talkies" were becoming the rage since the 1929 showing of "The Jazz Singer," the first motion picture with sound. The design and construction of sound movie photographic and projection systems became a major new outlet for the efforts of electrical engineers.

A number of companies that were to become electronic giants were already in place. RCA had 2,000 employees

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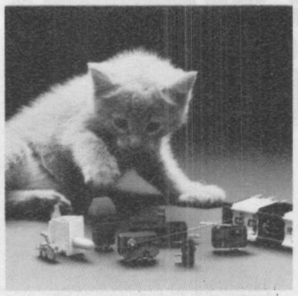

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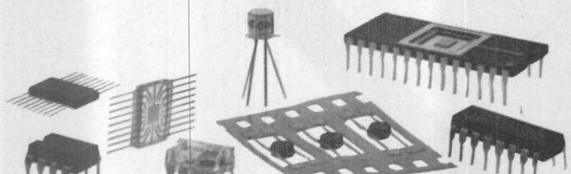

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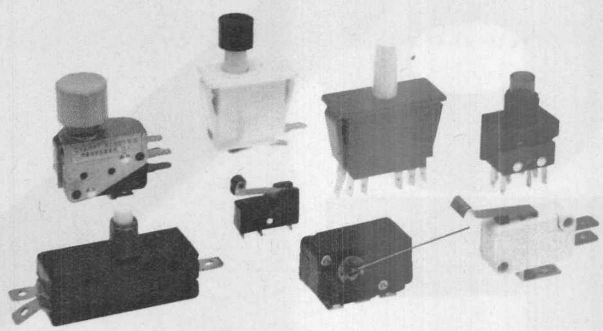

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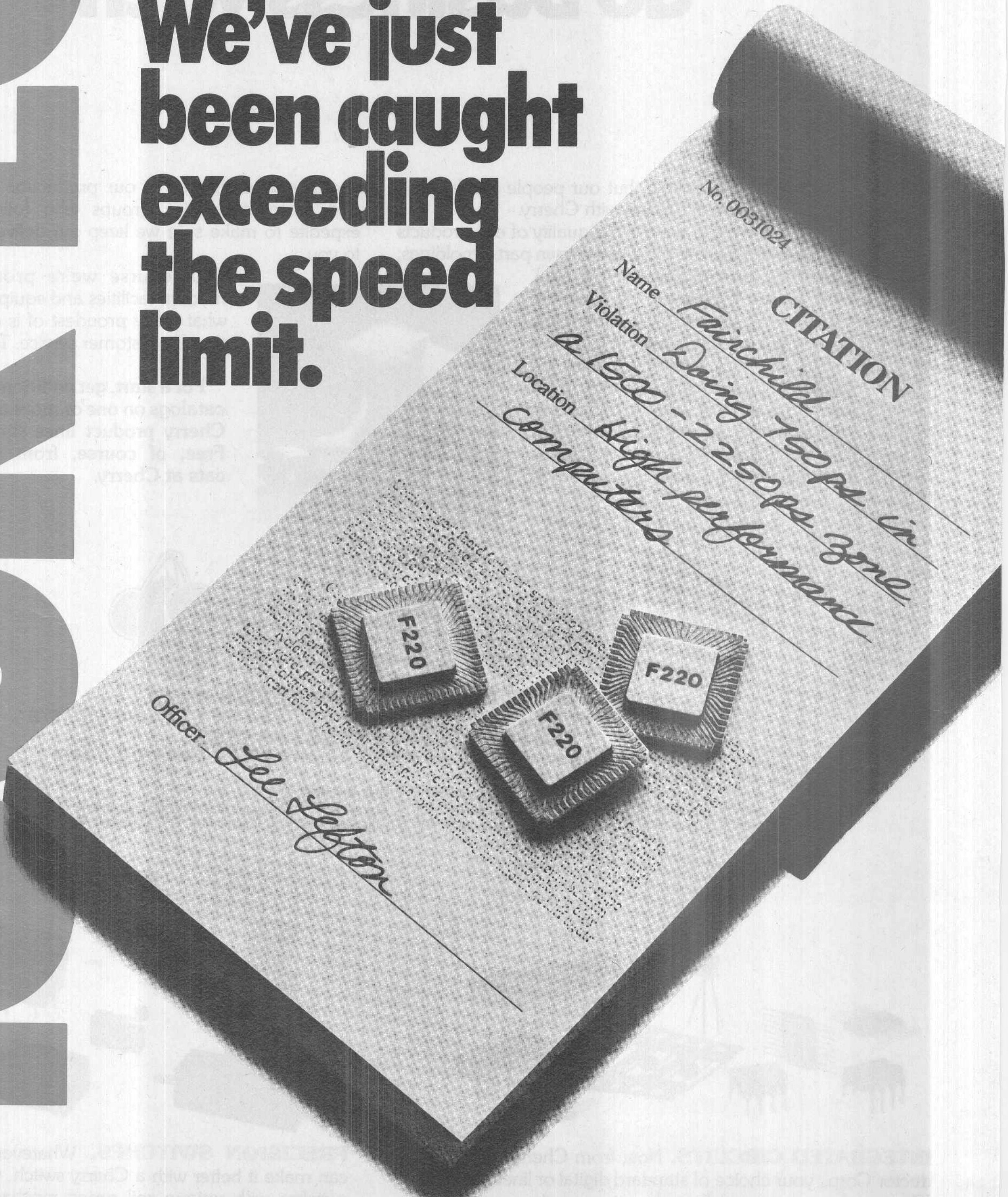


Realization. Here at Columbia University's Statistical Bureau, a Difference Tabulator built by International Business Machines Corp. in 1929 made use of ideas put forth by Charles Babbage early in the 19th century.

worldwide by the beginning of 1930. It had been formed by the General Electric Co. in 1919 to buy control of the Marconi Co. and to manufacture radio devices and systems developed by GE, Westinghouse, AT&T, and others. Just the year before, RCA had acquired the Victor Talking Machine Co. (phonographs and phonograph records), and it owned half of the National Broadcasting Co., as well as one radio station in New York and one in Washington, D. C.

GE had 87,800 employees, but the company's interest was more electrical than electronic. The Westinghouse Electric and Manufacturing Co., also a long established electrical firm, had 49,000 employees.

International Business Machines Corp. was firmly entrenched, with 4,400 employees and a string of companies that it had acquired. The corporate entity specialized in time recorders, tabulating systems, and weighing scales. With a technological base rooted in Herman Hollerith's electromechanical, punched-card tabulating machine, IBM was looking at the upcoming decades with optimism under Thomas J. Watson. Already the company had manufactured a statistical machine for Columbia University in 1929. Using registers for data retrieval and storage, this digital calculator—or difference tabulator, as it was called—brought to life many of the ideas propounded by the mathematician and inventor Charles Babbage nearly a century earlier. It influenced the 600 series of IBM multiplying machines that were introduced in 1931 and was a forerunner of the Mark I developed by IBM and Howard Aiken at the end of the decade.

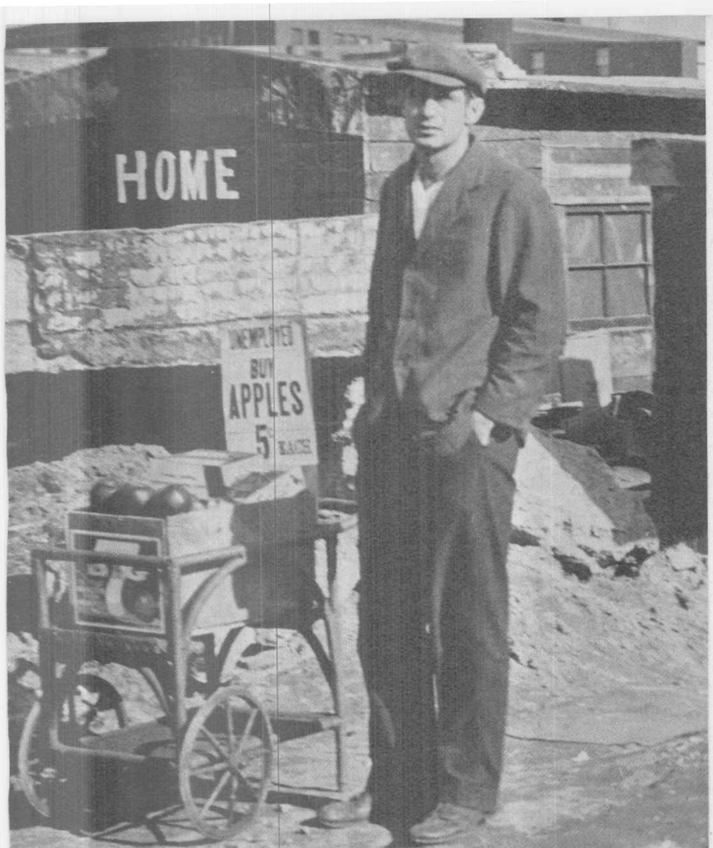
Much of the groundwork was being laid for the analog computer during this time and throughout the 1930s. Research was ardently pursued at the Massachusetts Institute of Technology under Vannevar Bush.

Radios and tubes were being turned out by companies like the Zenith Radio Corp., the National Union Radio Corp., Crosley Radio Corp., Perryman Electric Co., and De Forest Radio Corp. All of them except Zenith, which survives today as the Zenith Corp. in Chicago, became early victims of the perpetual "shakeouts" in the electronics industry.

Enough was happening constructively in the electronics industry amid the Depression for O. H. Caldwell, first chief editor of *Electronics*, to write in its first issue: "There will be nothing that the average man sees, hears, or buys but what will be controlled, regulated or affected in some important respect by an electronic tube!"

Certainly the average man was already experiencing the effects of the radio tube. Radio sets and radio broadcasting were big business. From about 9.5 million sets in use in July 1929, according to a Department of Commerce estimate, the total had climbed to 11.5 million six months later. By July 1, 1930, there were 13.5 million radio sets in use, both battery- and ac-operated. Lee de Forest, president of the Institute of Radio Engineers, told the institute's fifth annual convention in August 1930: "Radio has largely eliminated [newspaper] extras on prize fight results, and has shown a curtailment of interest in baseball news."

The radio sets did not come cheaply. Average prices reached a peak of $124 per set in 1927, according to figures published in the June 1930 issue of *Electronics*, declining somewhat to $110 in 1929. To buy one, an industrial worker had to invest nearly four weeks' wages,



Sight and sound. Wrapping up the Depression in one image, the apple peddler made his first appearance during 1930. Symbolizing the era in sound, sports columnist Bill Corum (left) and announcer Don Dunphy brought the fights to life for millions of listeners.

since in 1929 the average manufacturing wage was about $30 a week, or $1,500 a year.

The electrical engineer was much better off. In its May 1930 issue, *Electronics* published a chart compiled by the Society for the Promotion of Engineering Education. It compared the earnings of engineering graduates employed in the "radio" and "electrical" branches. The average salary at graduation was about the same for the two—$1,750 annually. But five years after graduation, the radio engineer was earning about $3,500 annually, while his electrical engineer colleague averaged $2,800, according to the chart.

"It is evident why many of the higher-class graduates are interested in linking their futures with that of radio," observed W. R. G. Baker, engineering vice president of the RCA Victor Co. of Camden, N. J., in an article accompanying the chart.

But as the Depression deepened, the future even for radio engineers became clouded. The January 1930 issue of the Proceedings of the IRE contained an announcement of an employment service for members that stated: "Beginning with the February 1930 issue, an advertising page of 'Engineers Available' will be published." The price: $2 per insertion per month.

Further evidence of the effect of the Depression was provided by the membership figures of the IRE. From about 6,600 engineers on the rolls at the end of 1930, the organization, which had been founded in 1912, showed a dip to 6,500 members in 1931, then a sharp drop to 5,350 the following year and finally a low of 4,250 in 1934. From there, the total crept back up to 5,750 members by the end of 1940 and, with the onset of World War II and U. S. involvement, to 7,020 in 1942.

The American Institute of Electrical Engineers, a much larger organization, had slightly more than 18,000 members in 1929 after reaching a high of 18,344 in 1927. But from there on, it was down, down. The low of 15,230 members was hit in 1935. Not until 1942 and the engineering efforts of the war years did the AIEE membership rebound to its 1927 level.

These declines were, of course, only mirror images of what was happening in the country at large. Unemployment in the U. S. had been extensive even during the seemingly good years of the 1920s. It rose as high as 5 million in that decade, was never lower than 1 million, and ranged from 1.5 million to 3 million. Most of the time anywhere from 4% to 7% of the labor force was unemployed, according to one estimate.

The Federal government reported 2.5 million workers unemployed in April 1930, the month *Electronics* was introduced. Other estimates went as high as 8 million. By 1932, it was widely reported that some 14.5 million people were out of work.

There were signs in the summer of 1929 that business activity was slowing, and after a mild renascence in the spring of 1930, the year finished at below 80% of the so-called normal point. Nearly 80% of the total value of stocks was wiped out. Industrial profits after taxes, which had been $8.3 billion in 1929, reached losses of $3.4 billion in 1932. Investment in the American economy fell from $16 billion in 1929 to $900 million in 1932.

Before the deep gloom set in, the Radio Manufacturers Association had exuded optimism. At the group's fifth annual convention in June 1929, its president had

declared that the radio industry was "in a healthy condition." He was wrong, and his 270 members were in trouble. The radio business reflected the condition of other industries in the country: the sales peak had passed; there were simply not enough people capable of buying what was being produced.

In June 1930, *Electronics* asked admonishingly in its editorial columns: "Are we heading once more into overproduction of radio sets? Will 1930 see a repetition of the serious surplus of radio receivers which made a nightmare of 1929, and spilled over into the spring dumping of 1930?"

In 1929 a total of 4.7 million radio sets had been manufactured, of which 4.2 million were sold, according to the magazine. "In 1930," it added, "every indication in the radio field, and in general business, points to restricted demand . . . Undoubtedly, 3.5 million is the figure to put down as representing top sales for 1930."

At the 1930 convention of the Radio Manufacturers Association, membership was down by 45 companies, and further declines were in the offing.

Not everyone saw the glut of radios resulting from economic conditions. De Forest, the so-called father of radio broadcasting, had another opinion: people had stopped buying radios because they were repelled by the advertising. In his inaugural address on Jan. 8, 1930, following his election to the presidency of the IRE, de Forest said he wished to "raise my voice in most certain protest against this revolting state of affairs."

De Forest had equally strong opinions about the motion picture industry and its talking pictures. "Here, both in studio recording and in theater reproducing methods and apparatus, is witnessed a most deplorable result of engineering indigestion," he asserted. "The profession has bitten off very much more than it could properly masticate in these few years."

He described the "made voices" of talking pictures as "perhaps clearly understandable but all of one timbre—and that wholly unnatural and unpleasing, as if emanating from wooden tonsils and fibre tongues." Of the music, he said: "The present shrieking noises, at best, are only a sad burlesque of fine music, painful to endure." He mourned the "thousands of musicians actually put out of employment by this loud speaking robot."

De Forest urged the radio profession "to concentrate every human effort upon this urgent and highly baffling talk of bringing back real music to the cinema and real voice to the theater screen—or, if not, let an outrageous and long-suffering public rise in righteous wrath and curse us."

There was some good news, too, in 1930: the pace of technological advance was accelerating. The negative-feedback amplifier was announced that year, although Harold S. Black actually had developed it at Bell Telephone Laboratories in 1927. Important as negative feedback is today, it "had all the initial impact of a blow with a wet noodle" in 1930, according to one of Black's laboratory assistants. It wasn't until 1932, when Harry Nyquist, also of Bell, recognized the importance of phase control in the feed-

Waste not. Trying to conserve in every way, this Depression man fixes his shoes at the East River near 10th Street in New York City.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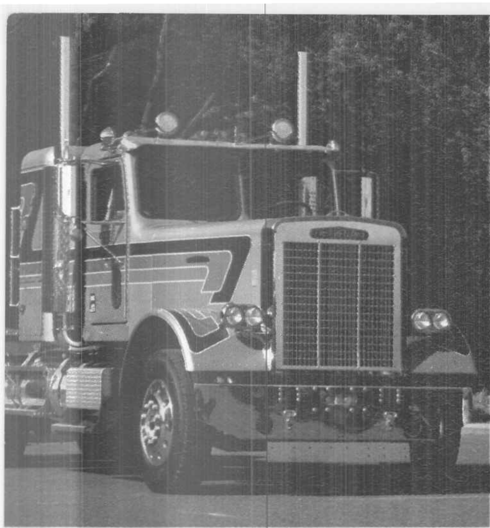


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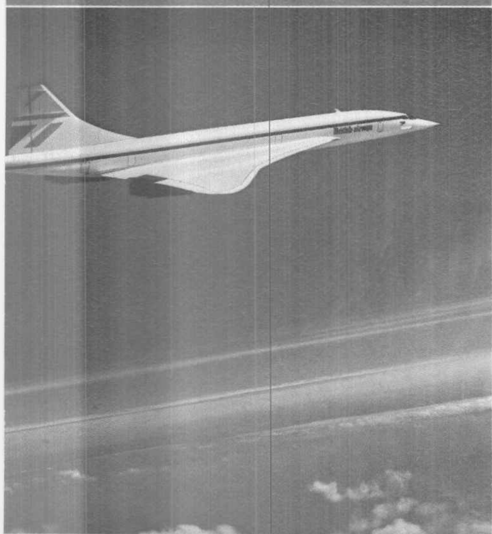


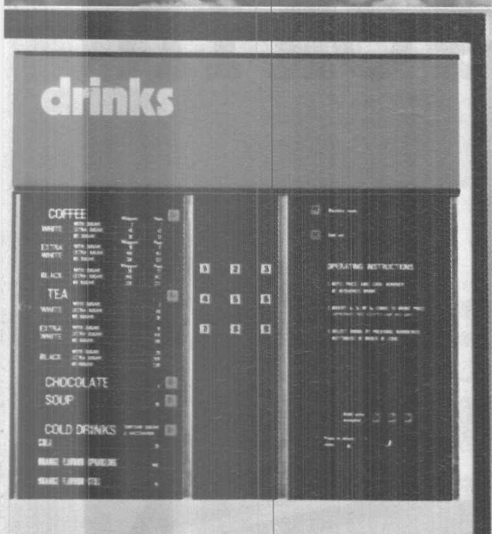
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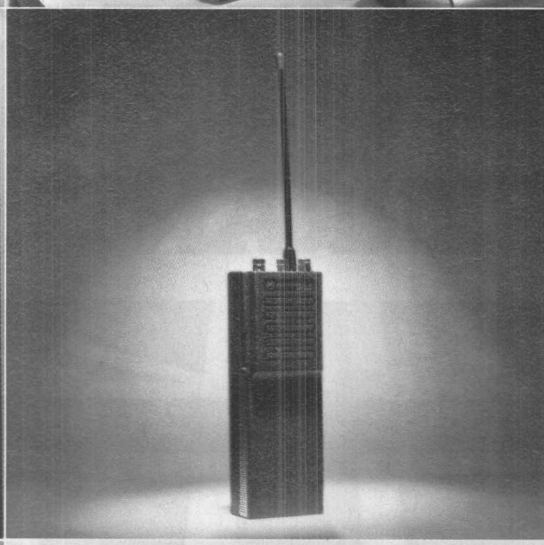

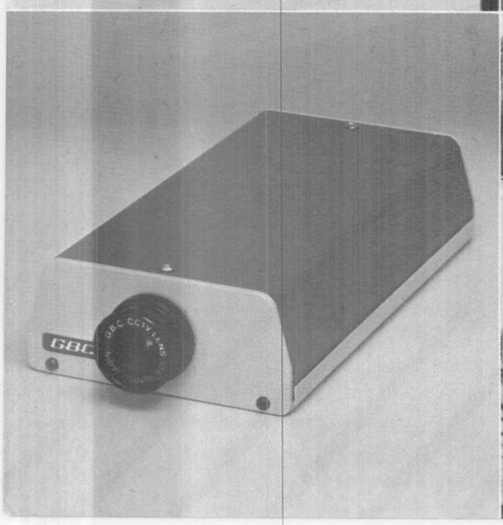
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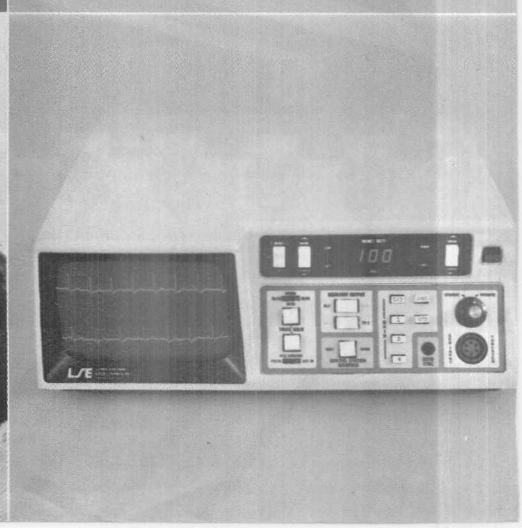
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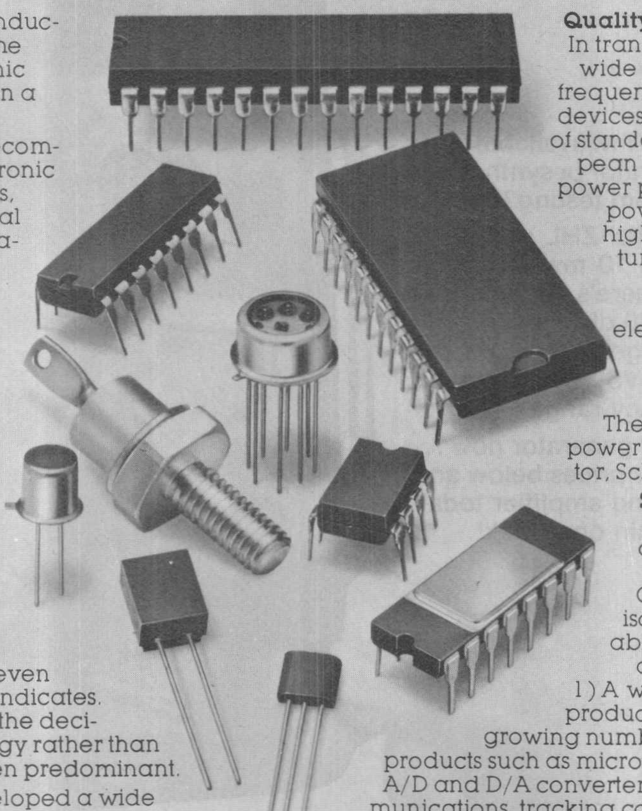

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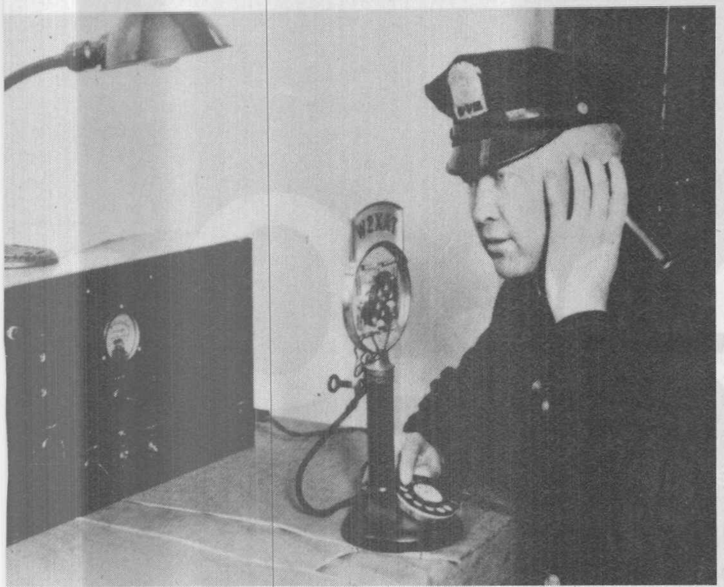

10-4. Not Broderick Crawford, but Patrolman H. H. Moon of the New Rochelle, N. Y., police uses radio to communicate with police cars. direct from headquarters. The dial serves to connect the police system with telephone lines for local and long-distance hookups.

back loop and invented the now famous Nyquist diagram, that negative feedback began to be widely appreciated. It is now not only used to make low-distortion amplifiers with stable gains but also is the basis of all automatic control systems.

Lest young engineers today think that nothing of much importance happened before the transistor, it is worth noting that in 1930 the superheterodyne receiver was already more than 10 years old, having been invented during World War I by Maj. Edwin Howard Armstrong while he was in France. Armstrong, who had also invented positive feedback (in the form of the regenerative receiver) and superregeneration, was hard at work on the development of frequency modulation in 1930. In July of that year he filed for the first of four fm patents, all of which were to be issued to him simultaneously on Dec. 26, 1933.

Television was also under intensive development. Vladimir K. Zworykin of Westinghouse had demonstrated in 1929 a television receiver containing his kinescope picture tube and had so impressed RCA's Sarnoff that the latter invited Zworykin to join RCA to make television a commercial reality. By 1930 Zworykin was in Camden as director of RCA's Electronic Research Laboratory, and in 1931 he and his staff developed an improved version of his iconoscope camera tube, one that was much more sensitive than the device he had patented years before in 1923.

Carrier-based telephony, too, was both well established and on the verge of great technical advance. Multiplexed open-wire lines had been widely used in the 1920s, and in 1929 Lloyd Espenschied and H. A. Affel of Bell Telephone Laboratories had developed a system based on coaxial cables, which are basic to most guided-wave carrier systems in use today.

One area of communications that was only beginning

Although the New York Harbor Police used spark-gap transmitters to communicate with police boats as early as 1916, technical problems had to be overcome before mobile receivers could be termed practical. Low sensitivity, high power consumption, ignition noise, and the need for frequent replacement of fragile tubes were the principal obstacles to the widespread use of radio receivers in cars and boats until 1928. That year a six-tube set was designed for the Detroit Police Department (see chapter 3). Automobile radios for the public soon followed and became quite popular in the 1930s.

Industrial electronics meant tubes and transducers in 1930. Electron tubes were doing heavy-duty work, such as controlling the amplitude and duration of output current in resistance-welding machines. Soon tubes began to replace the magnetic contactors and relays used to control motors, furnaces, and machine tools. To industry, the tube was panacea: not only was it fast and accurate, but it was also quiet, flexible, power-stingy, and safer than arc-prone mechanical contacts.

By 1930 most of the basic vacuum tubes known today were around, although all were to undergo considerable refinement. There were the diode, triode, tetrode, and pentode. The heptode, the hexode, and the pentagrid converter had yet to be developed.

The basic tube of 1930 was a glass envelope with a plastic base; the steel-envelope tube was not invented at General Electric until 1935. The base and pins of the tube were plugged into sockets. Components and interconnecting hookup wires were hand-soldered between terminals on the sockets.

Even before 1930 it was recognized that better wiring methods were needed for the mass production of radios. In 1925, for example, an inventor called Charles Ducas had patented a method of forming electroplated conductor patterns in copper, gold, or silver on a nonconductive base material. These metal-plated stenciled patterns were the forerunner of the printed circuit, but they were never applied commercially.

Another competitor of point-to-point wiring—one that was used commercially—had stamped brass conductors riveted to a bakelite panel. This system was employed in a six-tube receiver prior to 1930.

Components were undergoing great changes as *Electronics* was born. Wirewound resistors were giving way to carbon-composition devices, which offered both higher resistance values and better high-frequency performance. Paper capacitors were becoming available to replace mica units. And wet electrolytic units had been introduced for power-supply filtering.

To cap the burgeoning activity in electronics, Walter A. Shewart of Bell Telephone Laboratories published in 1931 his magnum opus, "Economic Control of Quality of Manufactured Product" and in so doing essentially invented what is now known as quality control. Shewart's work led to the founding of the American Society of Quality Control.

Electronics had indeed come of age as a manufacturing industry.

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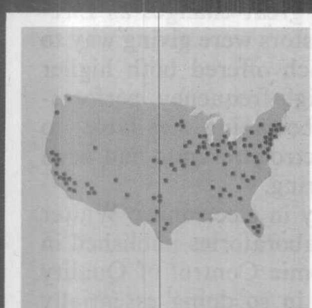
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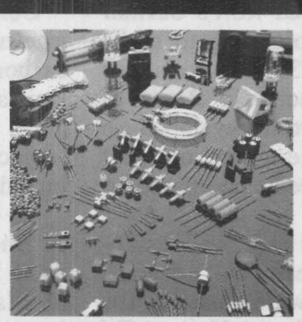
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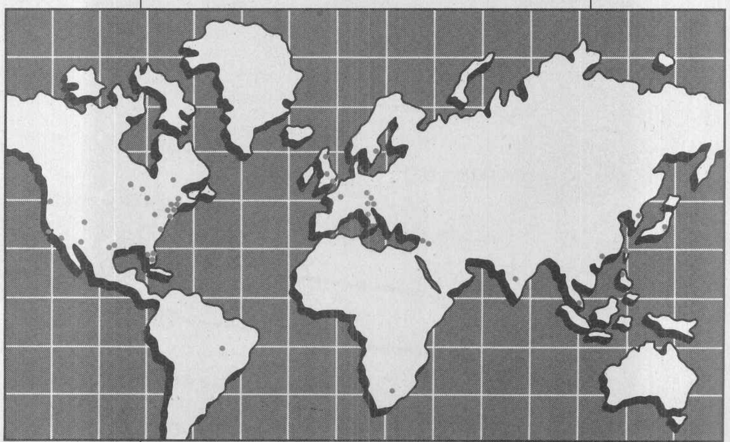

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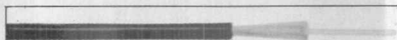
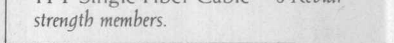


ITT Single Fiber Cable—*8 Kevlar strength members.*



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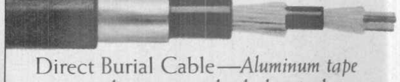
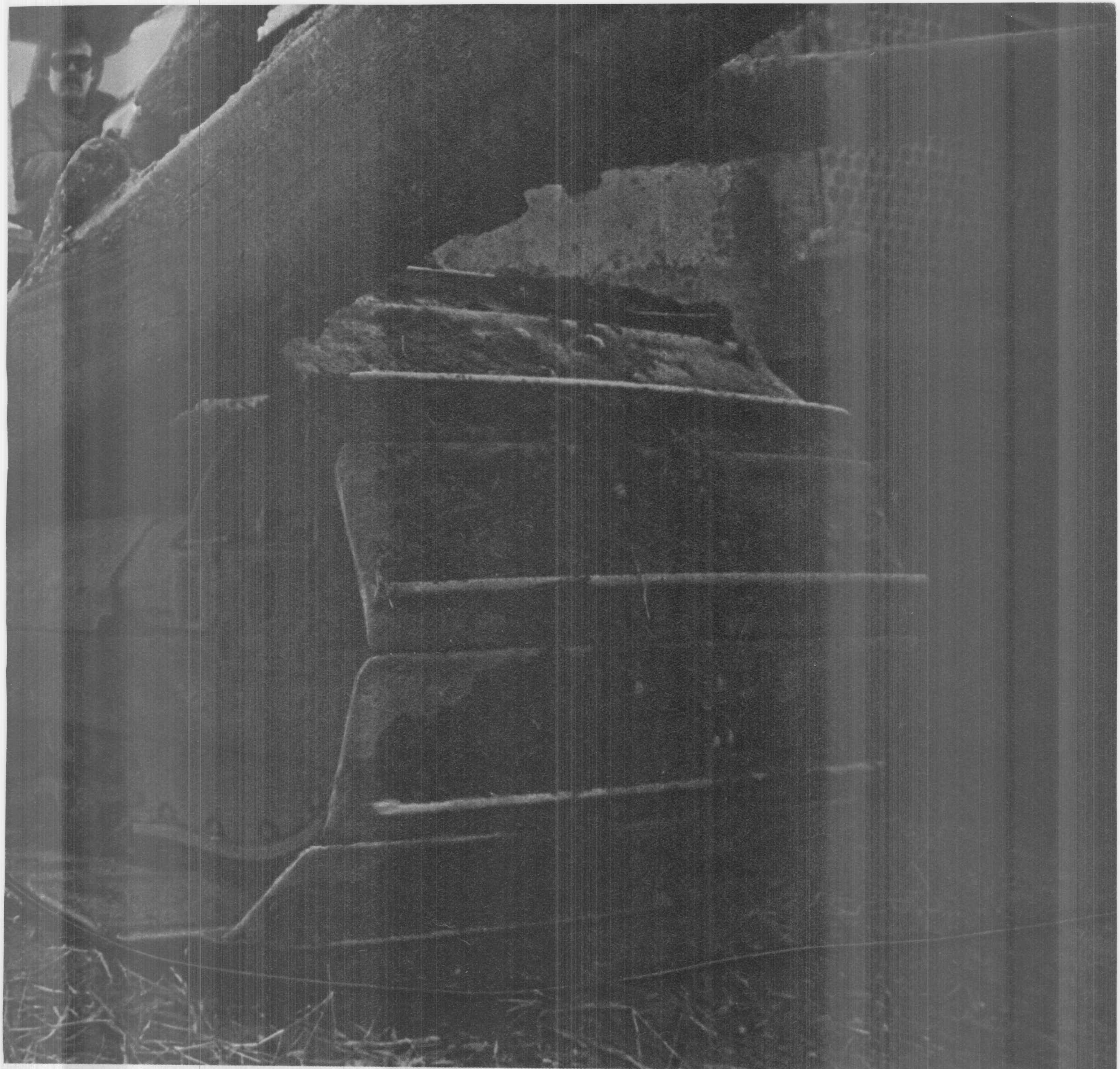


Direct Burial Cable—*Aluminum tape armor with an outer polyethylene jacket.*




following experiments are for the
of carrying by Electrification of the Carbon
from one side of the Carbon horseshoe
70
80

HOW TECHNOLOGY GOT THERE

ALTHOUGH IT WAS 1883 WHEN THOMAS EDISON DISCOVERED THE EFFECT THAT WAS TO BECOME THE BASIS OF THE ELECTRON TUBE, THE ELECTRONICS INDUSTRIES HAVE ROOTS THAT GO MUCH DEEPER. FOR EXAMPLE, A FORERUNNER OF THE COMPUTER WAS BUILT BY BLAISE PASCAL IN 1642. NEVERTHELESS, ELECTRONIC TECHNOLOGY AS IT IS KNOWN TODAY IS ESSENTIALLY A PRODUCT OF THE 20TH CENTURY, FOR IT HINGES ON A PAIR OF RELATIVELY RECENT DEVELOPMENTS—THE DEMONSTRATION OF RADIO BY MARCONI AND POPOV INDEPENDENTLY OF EACH OTHER IN 1896 AND THE INVENTION OF THE VACUUM TRIODE BY DE FOREST IN 1906.

Chapter 2

Strictly speaking, the age of electronics began in 1883 with the discovery of the Edison effect. In that year Thomas Alva Edison, in his efforts to increase the life of his early carbon-filament lamps, introduced a metal electrode into the vacuum envelope containing the glowing filament. He discovered that when a positive voltage was applied to the electrode, a current flowed across the vacuum between it and the filament. This phenomenon—the great inventor's only fundamental scientific discovery—is the basis of all electron tubes and of all electronics up to the solid-state era.

But Edison did not pursue his discovery. Some critics have taken this failure to follow up as proof that he was only a persistent tinkerer and not a first-class scientist. In Edison's defense, historians point out that he was extremely busy with many developments around this time: the pioneering Pearl Street electrical generating station had opened in 1882, and Edison was involved in 1883 with financial, managerial, and technical trouble-shooting. He did publicize his findings on the Edison effect, and he described the discovery in a patent.

Nevertheless, from 1883 to 1904 neither Edison nor anyone else exploited the effect to make a useful vacuum tube for detecting or amplifying electrical signals. Perhaps there was not sufficient motivation. Although the telephone could have benefited from the invention of a suitable amplifier—as it was to eventually—it was capable at the time of profitable operation without one. Radio, on the other hand, was not. And radio was also still struggling for an identity.

In 1896 in Pontecchio, near Bologna, the Italian Guglielmo Marconi used grounded antennas to send telegraph signals through the air over a distance of about 2½ kilometers. In St. Petersburg, Russia, that same year, Aleksandr Stepanovich Popov independently sent possibly the first radio message, "Heinrich Hertz," over a distance of 300 yards. Long-distance wireless telegraphy took a few more years. Marconi established radio communication between France and England in 1899. In 1901 he made radio waves cross the Atlantic from Poldhu, Cornwall, to St. John's, Newfoundland.

Radio, of course, did not begin with Marconi and Popov—it only seems that way. Like many other advances in electricity and magnetism, it had its origins in the discoveries and inventions of Michael Faraday and in the work of the mathematical genius, James Clerk Maxwell. Among Faraday's many discoveries was his elucidation in 1831 of the principle of electromagnetic induction. In 1832, looking into the future with remarkable clarity, he wrote:

"I am inclined to compare the diffusion of magnetic forces from a magnetic pole to the vibrations upon the surface of disturbed water, or those of air in the phenomenon of sound, i.e., I am inclined to think the vibratory theory will apply to these phenomena as it does to sound, and most probably to light."

Maxwell agreed. Progress was slow, however, and it was not until 1855 that he published "On Faraday's Lines of Force" or until 1864 that he gave the world his startling "A Dynamical Theory of the Electromagnetic Field." This paper presented what we now call Maxwell's equations, explained all of the known phenomena of electromagnetism, and predicted that radio waves could exist and would travel at the speed of light.

In 1887 Heinrich Hertz proved experimentally that Maxwell was right. Using a spark-gap transmitter and a loop antenna with a small gap in it as a receiver, he transmitted and received radio waves in his laboratory in Karlsruhe, Germany. More than that, he used a reflecting arrangement to detect standing waves and showed that the waves obeyed all the laws of geometrical optics, including those of refraction and polarization. No wonder Popov's first message was Hertz's name.

Thus although its beginnings lay early in the 19th Century, it was not until the beginning of the 20th that radio advanced far enough to make the world realize that it needed a decent amplifier.

If discovery of the Edison effect was the first step on the road to such an amplifier, the second step came in 1904 when John Ambrose Fleming invented the vacuum diode. Fleming, since 1882 a consultant to Edison Electric Light Co. in London, had met Edison personally in 1884 and learned about the Edison effect soon after its discovery. Fleming described his thermionic valve as a rectifier of high-frequency alternating currents. And that's what it was. Like cat's whisker crystal detectors and other receiving devices of the day, it rectified radio-frequency waves but it could not amplify them.

The third step on the road to amplification was taken by Lee de Forest. On Oct. 25, 1906, he applied for a patent on a three-element vacuum tube—the famous audion. This tube was similar to Fleming's valve, with one important difference: it had a control grid between the filament and the anode.

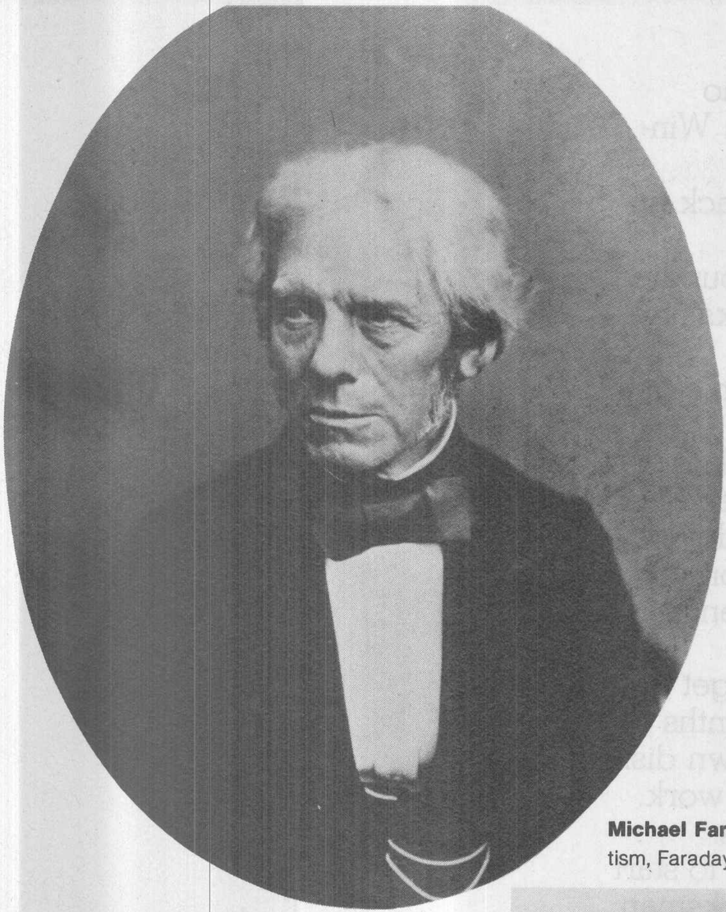
Today we think of triodes as amplifiers. But de Forest's early devices had such low gains that they were little better than diodes. Something was needed to make the audion into a practical amplifier. It was six years in coming, but when it came it marked the beginning of radio and of modern electronics.

This device was Edwin Howard Armstrong's regenerative circuit. It constituted not only the sensitive receiver that everyone was looking for, but as a bonus, it was also the first nonmechanical generator of clean continuous-wave signals.

Regeneration—or positive feedback—involved coupling a portion of the plate-circuit signal back into the grid circuit to increase the amplification of a triode. With sufficient feedback, of course, the amplifier became an oscillator. First set up and operated on Sept. 22, 1912, Armstrong's regenerative circuit was quickly adopted by industry, although frequently in violation of Armstrong's patent. Transcontinental telephone service was established between New York and San Francisco early in 1915 based on regenerative repeaters, and later that same year, in a historic experiment, voice signals were successfully transmitted from Arlington, Va., to Paris. This experiment used the regenerative circuit in both its transmitter and receiver.

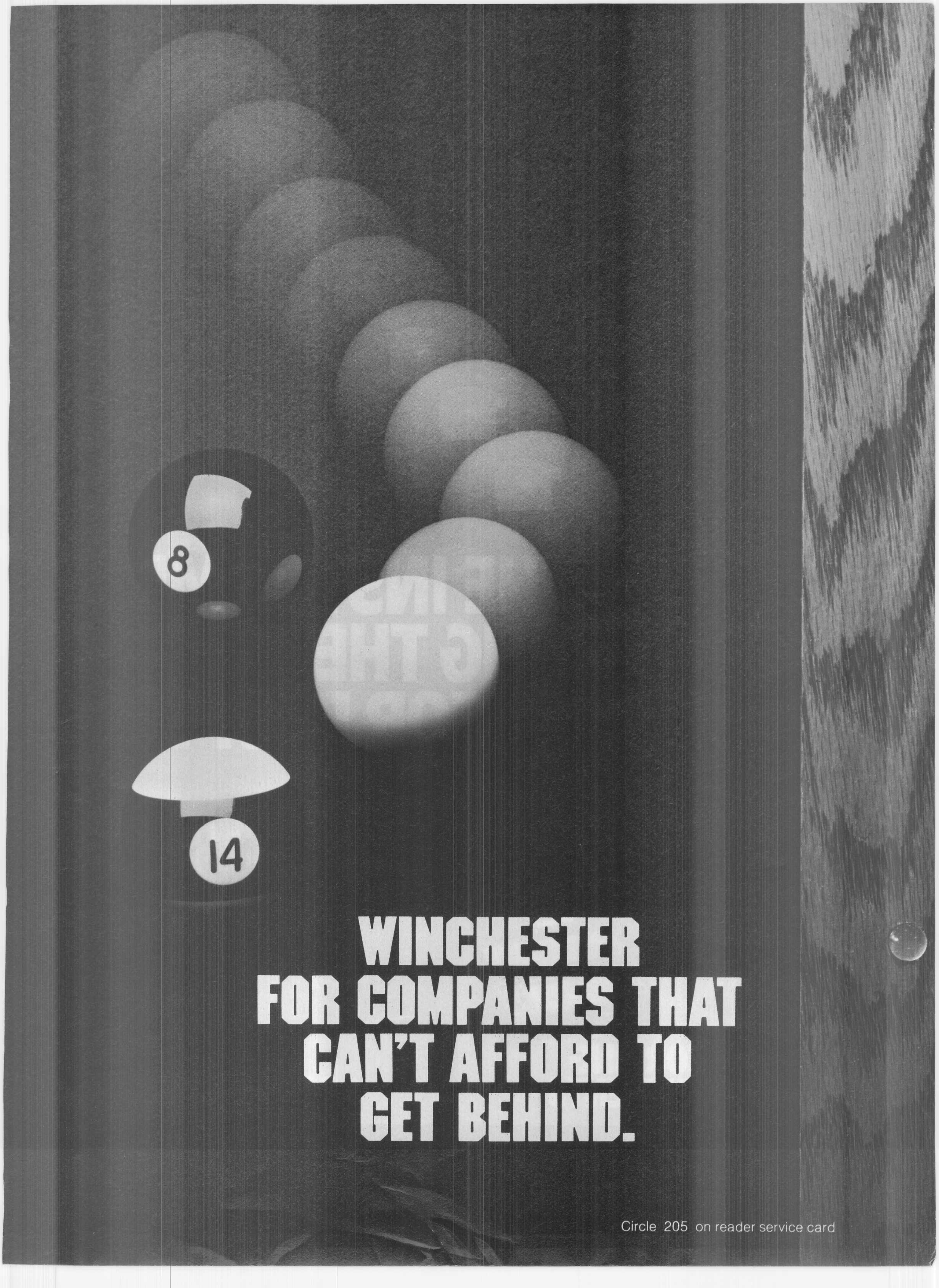
There was early recognition by both Irving Langmuir of General Electric and Harold Arnold of Western Elec-

Guglielmo Marconi. Often called the inventor of radio, Marconi was actually the first man to use grounded antennas. In 1896, he sent radio signals some 2.5 kilometers.



Michael Faraday. Quite likely the greatest experimenter in electromagnetism, Faraday predicted the existence of electromagnetic waves in 1832.

Thomas Edison. It was probably his preoccupation with the first commercial generating station (on Pearl Street in New York) that prevented Edison from pursuing his discovery of the Edison effect and going on to invent the electron tube.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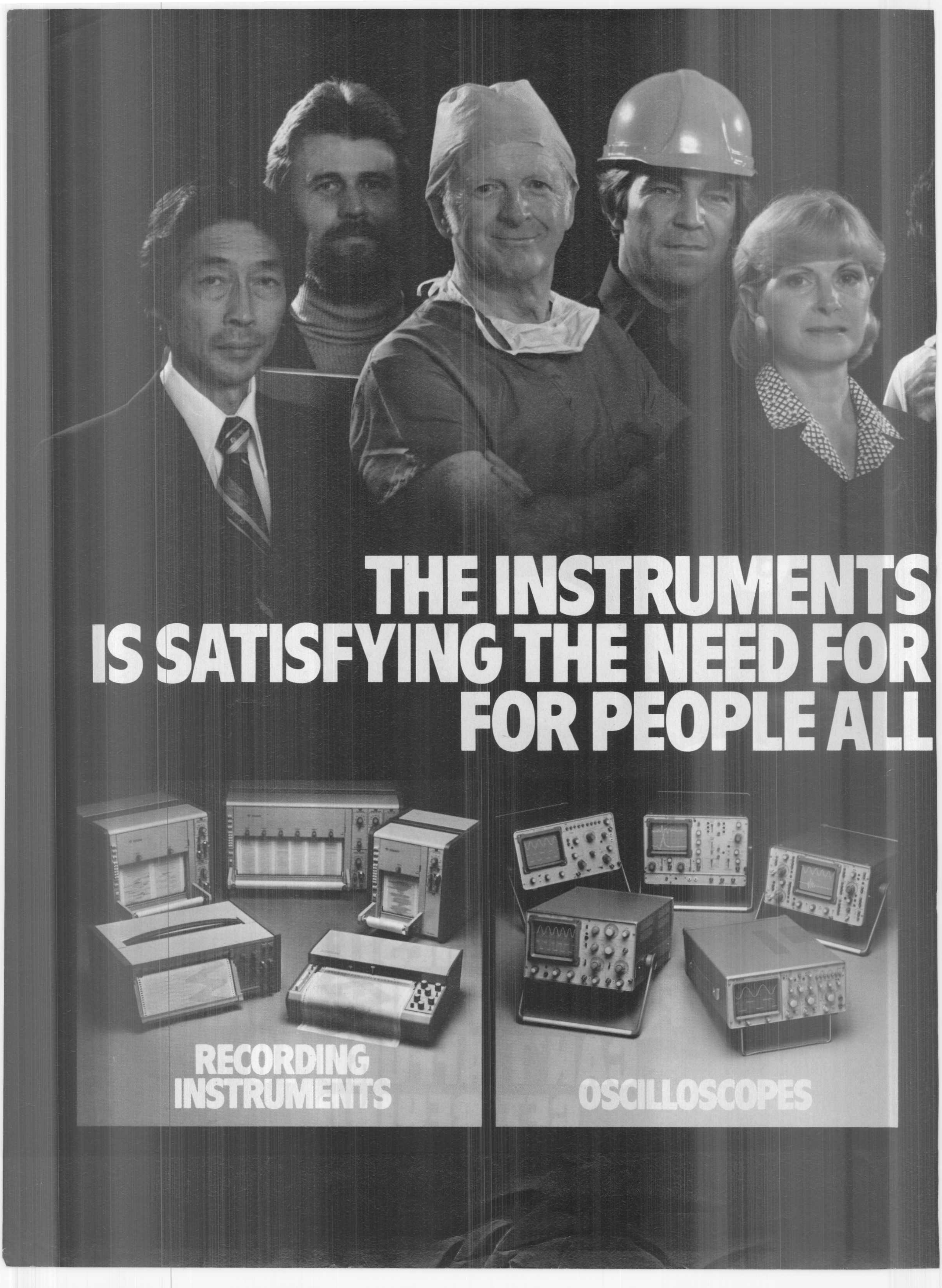
Circle 205 on reader service card


THE INSTRUMENTS
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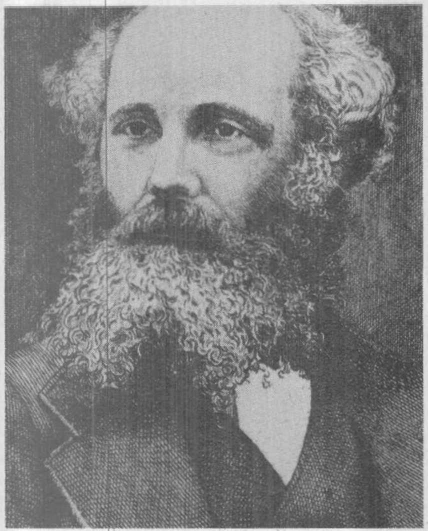


James Clerk Maxwell. This man invented field theory and calculated that radio waves would travel at the speed of light.

Heinrich Hertz. In a series of experiments in 1887 Hertz demonstrated the existence and nature of electromagnetic radiation.

John Fleming. He learned about the Edison effect from Edison himself in 1884 and went on to invent the vacuum diode in 1904.

tric (later the first director of research at Bell Telephone Laboratories) that improving the vacuum in the triode would make it a much better amplifier. Indeed, the tubes used in the transcontinental link in 1915 were special hard-vacuum devices made by Western Electric.

From this point onward, developments came at an ever-increasing pace. Single-sideband transmission, the superheterodyne, radio navigation, carrier systems for telephony, and the flip-flop circuit were just some of the important achievements between 1915 and 1920.

But two other modern electronic marvels—television and the computer—though far from ready, had been evolving for some time. It is perhaps a good idea to look back at their nonelectronic origins before seeing how they were affected by the vacuum tube.

The need for rapid and accurate solutions to the tedious mathematics involved in setting up mathematical tables for astronomers and naval navigators may have been the greatest stimulus in the middle of the 19th Century to the development of digital calculating machines. Earlier attempts at building calculators were aimed at the man of business who had long columns of figures to add and subtract, but who had few, if any, nonlinear functions to solve. And although work on analog machines to help in the calculation of tidal functions began in the latter half of the 19th Century, little progress was made toward the analog computer until the middle of the 20th Century.

The earliest mechanized computer was no more than an adding machine that could both add and subtract; but it could neither multiply nor divide. Built by Blaise Pascal in 1642, this machine was an aid in adding columns of figures in his father's office. His calculator had number wheels with parallel, horizontal axes. The positions of these wheels could be determined and their sums read through windows in the covers. Numbers were entered by horizontal dial wheels coupled to the number wheels by pin gearing. Most of the number wheels were geared for decimals; a carry ratchet coupled each wheel to the next higher place.

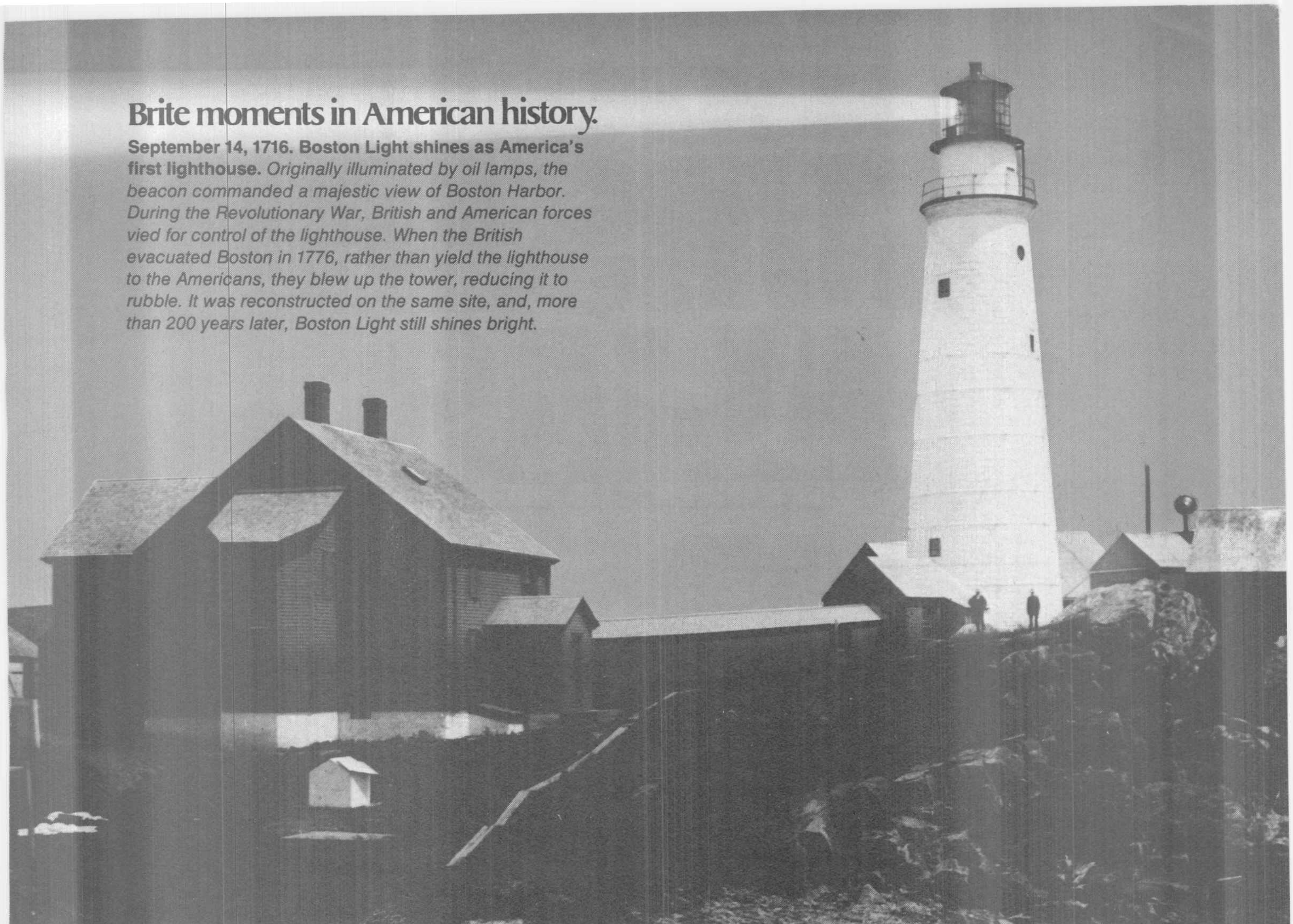
Pascal's machine is said to have been predated by one built by Wilhelm Schickhard of Tübingen, Germany, between 1623 and 1624, although this claim has never been fully substantiated.

In 1673 Gottfried Wilhelm Leibniz, the German philosopher and mathematician, completed a calculator that used a device known as the Leibniz wheel. It allowed not only automatic addition and subtraction, but also multiplication and division. Machines using a version of the Leibniz wheel were employed through World War II.

However, not until 1820, when Charles Xavier Thomas introduced his Arithometer, was it proved that calculators performing the four basic arithmetic operations could be manufactured commercially; and this was not truly done on a large scale until the latter part of the 19th Century.

Perhaps the most significant work with early digital computers was done by the English mathematician Charles Babbage with funding from the British government. In 1823 Babbage began work on his Difference Engine, a special-purpose calculator to help the British navy draw up various nautical tables. These could be tables of multiplication, logarithms, sines, and cosines, or of physical measurements and observations.

Babbage's machine was to perform all arithmetic operations using 20-digit registers and delivering a printed output. But the mathematician never fully completed his work on this Difference Engine, and in 1833 he started work on another idea that he failed to bring to fruition: the Analytical Engine. This machine was conceived as a general-purpose computer, very close in design to the Mark I, which was built at Harvard University a century later, in the 1930s. Babbage



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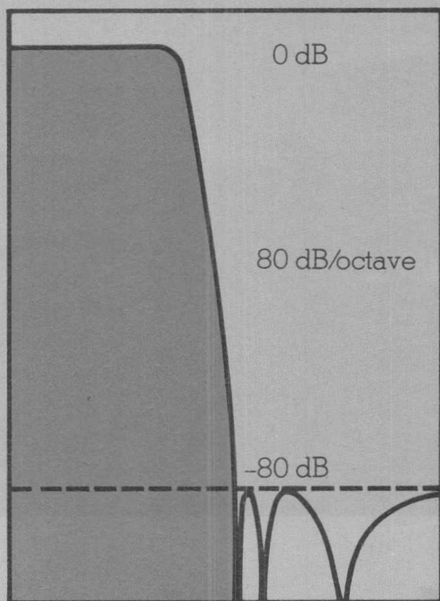

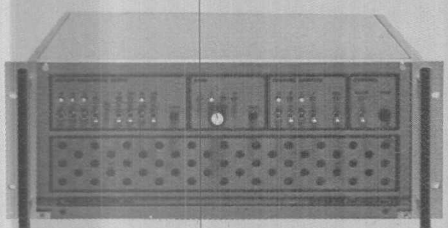

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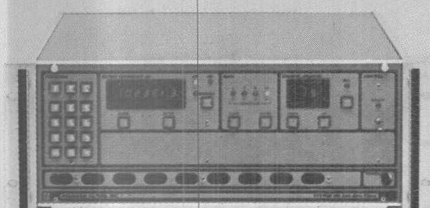

Precision 636
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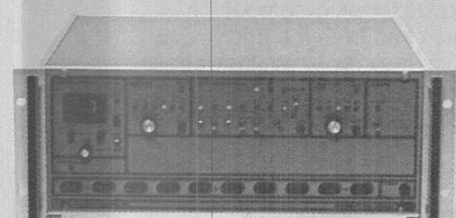

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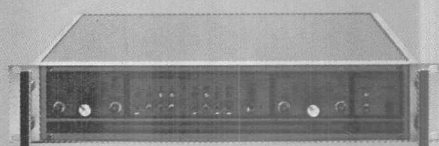
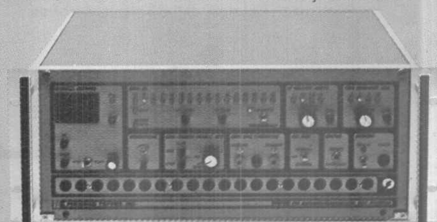


Precision 602
Two channels. 124 cut-off frequencies.



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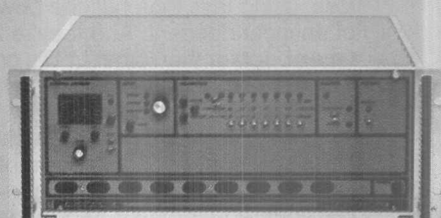

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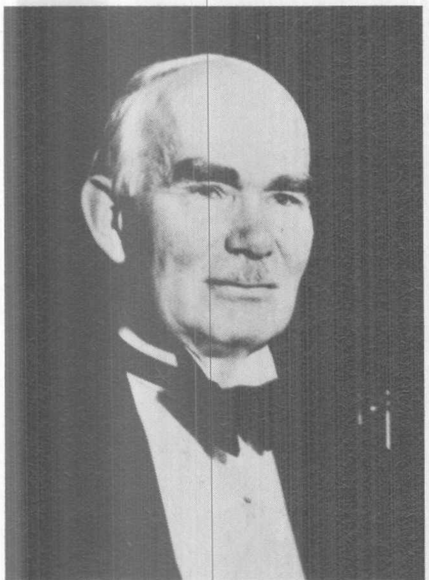


Lee de Forest. By putting a grid into a diode de Forest made one of the century's most important inventions—the triode.

Irving Langmuir. Shown with Willis R. Whitney, Langmuir (holding triode) advanced electronics by explaining the space-charge phenomenon in electron tubes.

foresaw the need for two distinct units—the store (or memory), where information and instructions were entered into the machine by punched cards, and the mill (or processing unit), where operations were to be performed by use of the stored information and instructions. Babbage had taken the idea of punched cards from Joseph Marie Jacquard, who invented an attachment to the loom in 1805 that automated the weaving of patterns. Jacquard used a series of cards with holes punched in them to represent the desired patterns. The holes allowed hooks to come up through the cards and pull warp threads down, so that when the shuttle passed through it went over certain preselected threads and under others.

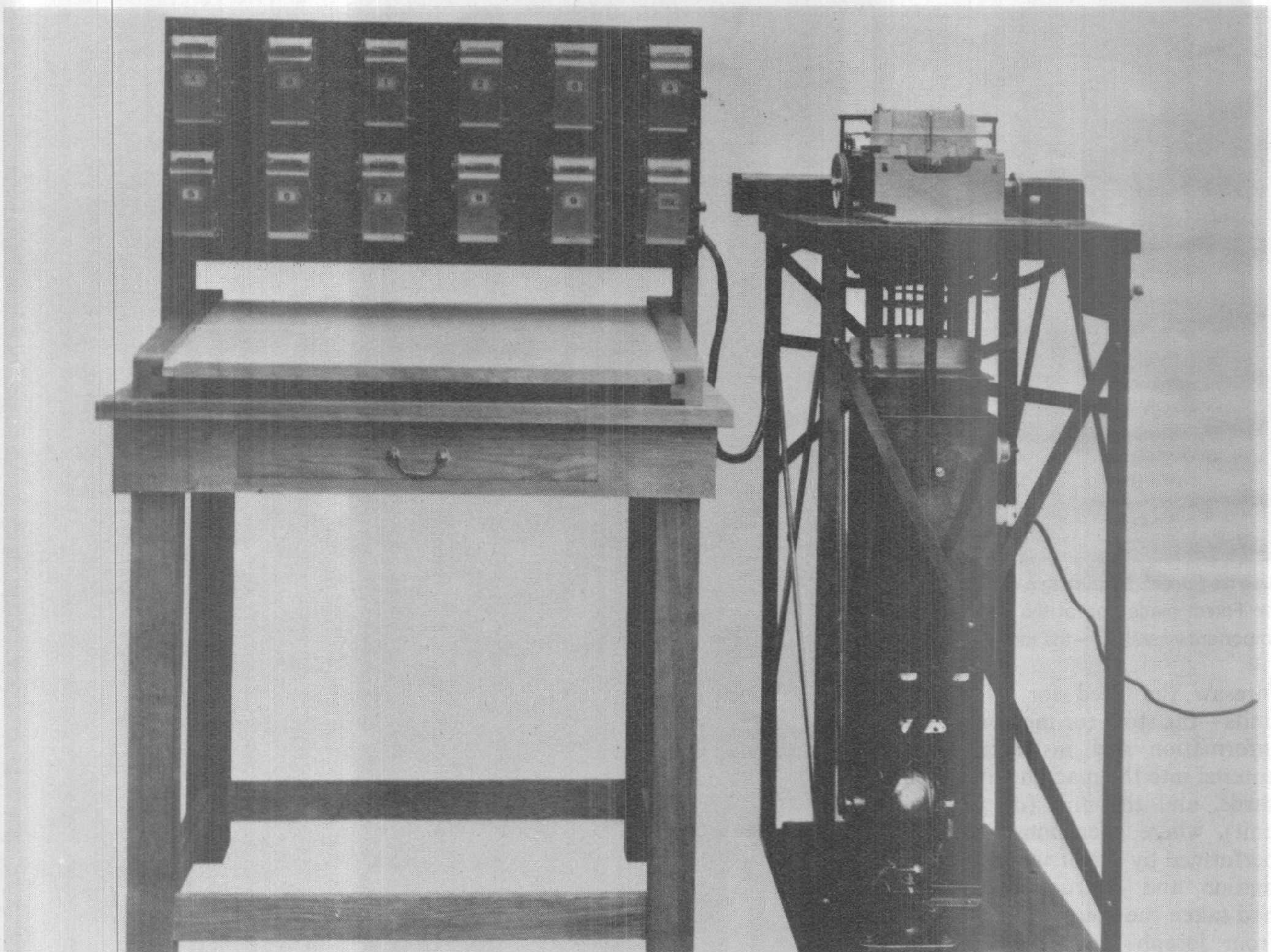
Babbage's Analytical Engine was to hold 1,000 words of 50 digits each, and when random access to tables of functions was required, the machine would ring a bell to alert the operator that additional data was needed.

A machine based on Babbage's design for the Difference Engine was built by Pehr Georg Scheutz in Sweden in 1854, but it took another hundred years for a working model of the Analytical Engine to be built by International Business Machines.

Formal logic, so necessary for the workings of digital computers, could not be satisfactorily explained mathematically before George Boole. In 1848 the English logician published "The Mathematical Analysis of Logic" and in 1854 "An Investigation of the Laws of Thought," the foundation of what is now symbolic logic. With the theories expounded in these writings, it was possible to express logic in very simple algebraic systems. The equation $x^2 = x$ for every x in the system is basic to Boolean algebra and has only 0 or 1 as an answer in numerical terms. Thus modern computers can make use of this binary system, with their logic parts carrying out binary operations.

The year 1890 marked the beginnings of two modern computer companies: Burroughs and IBM. In that year William S. Burroughs invented the Adding and Listing Machine—a very popular office calculator—and Herman Hollerith helped solve the compilation problems of the 1890 United States Census with an early data processor. Hollerith went on to form the Tabulating Machine Co. in 1896 to make both the processing machines and the cards they used. In 1911 this company joined with one that manufactured scales and industrial time clocks to form the Computer-Tabulating-Recording Co. In 1924, under Thomas J. Watson, the latter company became the International Business Machines Corp.

Hollerith's machine had three parts: a tabulator using clocklike devices that received electrical signals from reading brushes; a sorter box with 24 bins electrically connected to the counters in the tabulator; and a hand-operated punch cards for that were $6^5/_8$ by $3^1/_4$ inches and had 288 locations where holes could be punched. Normally all the lids on the bins were closed, but when a hole was sensed, an electrical circuit was completed that allowed the latch holding the lid to spring open. The card was then slipped into the bin by hand. It was several



Computer forefather. This early Hollerith sorter and counter was one of the first products of the Tabulating Machine Co. The company, which was founded in 1896, became the Computer-Tabulating-Recording Co. as the result of a merger in 1911. It is doing nicely today as IBM.

years before Hollerith was able to automate this part of the process.

James Powers, an engineer in the census shop, was commissioned in 1907 to develop an automatic card-punching machine, and in 1911 he formed the Powers Tabulating Machine Co., a principal competitor with the Computer-Tabulating-Recording Co. for some years. In 1927 Powers' company merged with Remington-Rand, which later combined with Sperry Gyroscope in 1955.

Unlike their digital counterparts, analog calculators did not come into their own until the 1930s under Vannevar Bush at the Massachusetts Institute of Technology. Early work on analog computers had been done at the end of the 19th Century by two English brothers, James and William Thomson. James Thomson was responsible for the design of a planimeter, which used a ball and disk integrator. William Thomson (Lord Kelvin) used this integrator in a harmonic analyzer and a tide predictor. He later went on to explore the idea of a differential analyzer, although he did not build one because of technical difficulties.

Unlike digital computers—which started out as mechanical devices and then went through a brief electromechanical period during the 1930s, finally becoming electronic only in the 1940s—television was an electrical medium from the its very beginnings.

Attempts to send images over distances with the use of electricity date to 1876, the year Alexander Graham Bell invented the telephone. At that time it was already known that the resistivity of selenium varied with the amount of light falling on it. Thus as soon as Bell made it clear that complex signals could be transmitted over a distance, inventors and would-be inventors began trying to develop means of "seeing by electricity," as the title of one paper put it at the time.

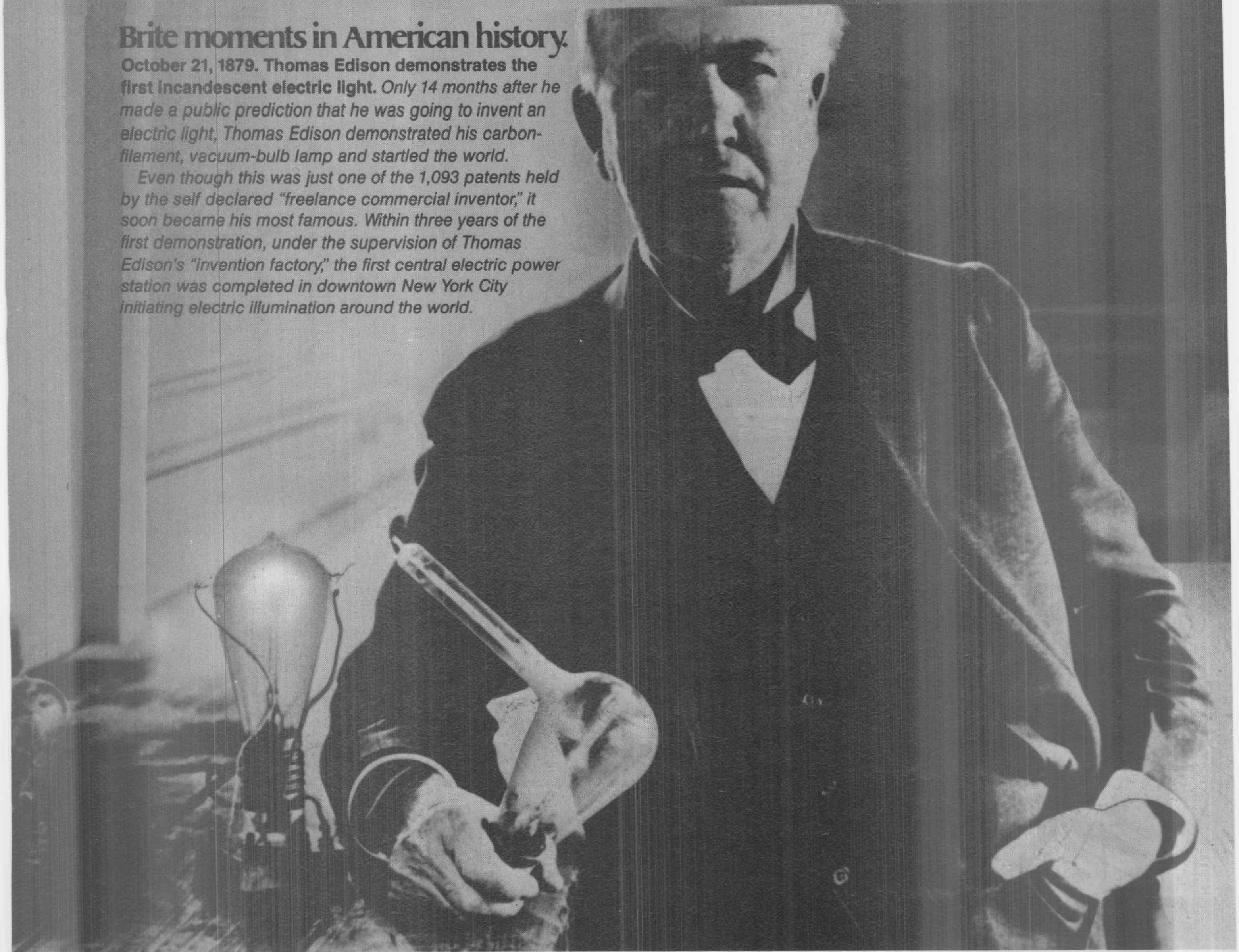
Some of the schemes involved the use of a mosaic of selenium detectors: others called for scanning the image mechanically with one or more selenium points. Reproduction was to be by anything from the movement of a pencil to electrochemical action on a piece of chemically treated paper at the receiver.

The first television invention that had practical consequences was the "electrical telescope," patented by Paul Nipkow in 1884. At the heart of his camera was the now famous Nipkow disk. It had 24 holes equally spaced along a spiral near the periphery of the disk. The image to be transmitted was focused on a small region at the disk's periphery, and the disk was made to spin at 600 revolutions per minute. As the disk rotated, the sequence of holes scanned the image in a straight line. A lens

Brite moments in American history.

October 21, 1879. Thomas Edison demonstrates the first incandescent electric light. *Only 14 months after he made a public prediction that he was going to invent an electric light, Thomas Edison demonstrated his carbon-filament, vacuum-bulb lamp and startled the world.*

Even though this was just one of the 1,093 patents held by the self declared "freelance commercial inventor," it soon became his most famous. Within three years of the first demonstration, under the supervision of Thomas Edison's "invention factory," the first central electric power station was completed in downtown New York City initiating electric illumination around the world.



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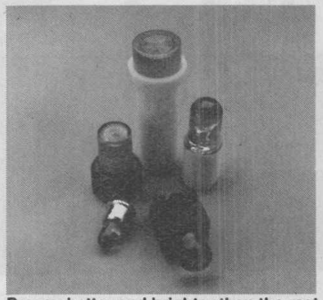

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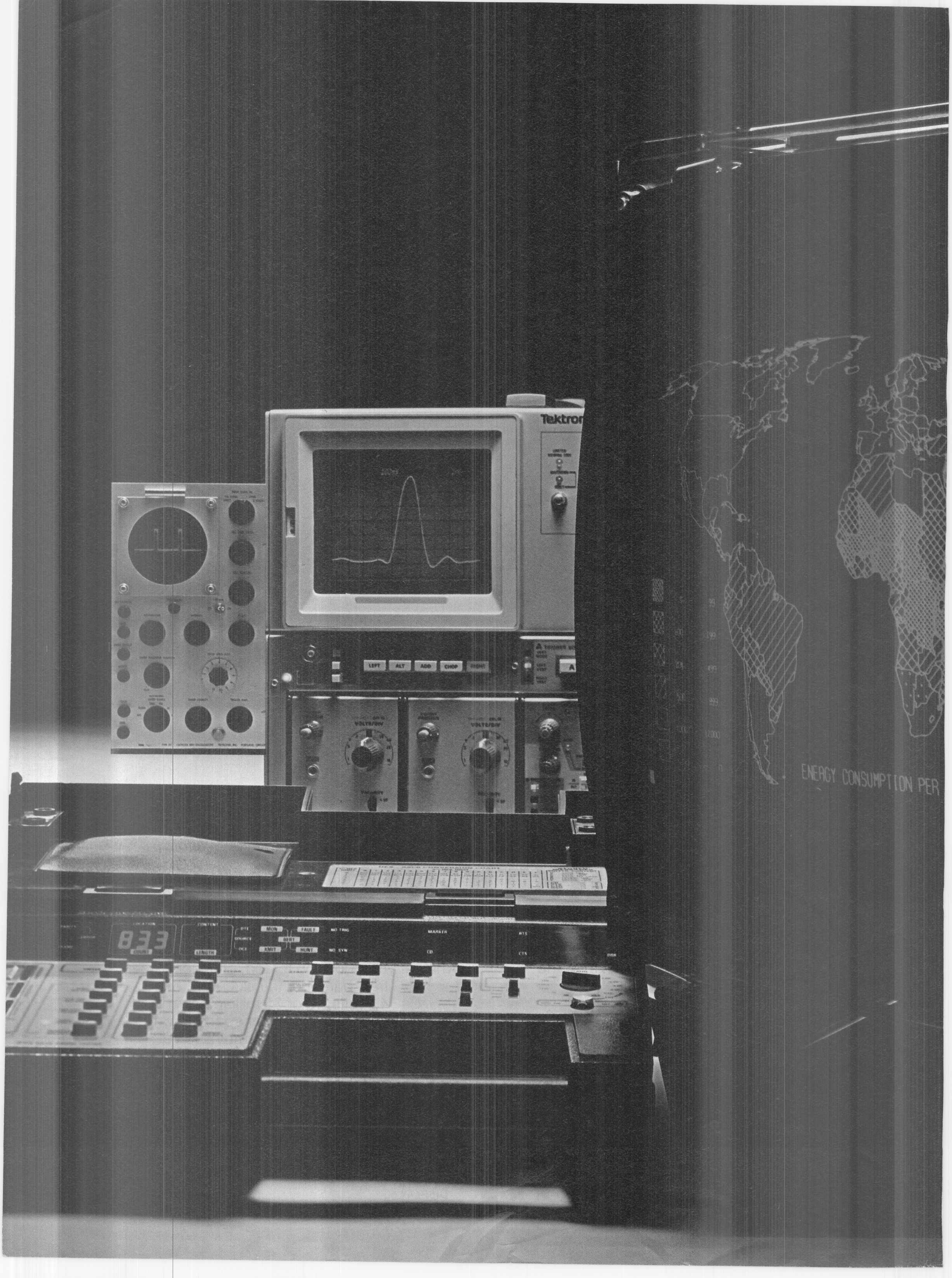
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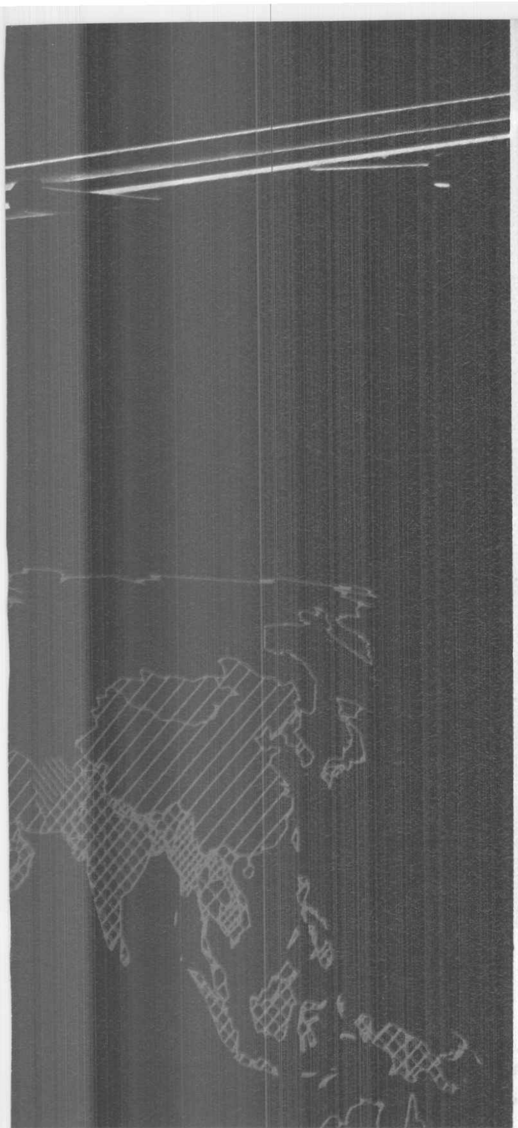
ENERGY CONSUMPTION PER



Fifty years of foresight.

Year after year, Electronics reports new technological breakthroughs.

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Electronics has served as an intelligent observer, analyst and reporter of our industry, performing a very important function to any company that has made an institution out of innovation. Through the pages of Electronics, volume after volume, the Tektronix commitment to customer needs has been well represented.

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This year we celebrate Electronics with a glimpse at the past and an eye on the promise of the future.

Versatility...Plus

The Tektronix Type 511 is a portable wide band oscilloscope providing facilities formerly available only in very expensive, cumbersome instruments.

Tektronix Type 511 Oscilloscope

SWEEP CHARACTERISTICS

Continuously variable .1 second to 1 microsecond (10 cm. deflection).
Direct reading sweep speed dial.
Choice of triggered, recurrent or single sweeps at all speeds.
Triggers on sine waves to 10 mc. or pulses over .05 microsecond.
Any 20% of sweep may be expanded 5 times.
DC coupled PP amplifier for external sweep input.

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Amplifier Bandwidth 10 mc., 1 stage; 8 mc., 2 stages.
Rise Time .04 microsec., 1 stage; .05 microsec., 2 stages.
Maximum Sensitivity .27 V/cm. (Peak to Peak).
Input Impedance Direct 1 meg., 40 mmf.; Probe 10 meg., 11 mmf.

MISCELLANEOUS

Calibrating voltage 0-1, 0-10, 0-100 volts, 60 cycles.
CRT 5CP1A, 5CP7A or 5CP11A operating at 3 kv.
Direct connection to all plates from side panel.
Total weight 65 pounds, self contained.

Price $795.00 f.o.b. Portland

Your inquiry will bring more detailed information and name of the nearest Field Engineering Representative.

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Electronics, we congratulate you.

The 1948 issues of Electronics carried this ad for our first oscilloscope, the 511. We've developed those original technologies, and pioneered new ones to create products as revolutionary today as the 511 was then.

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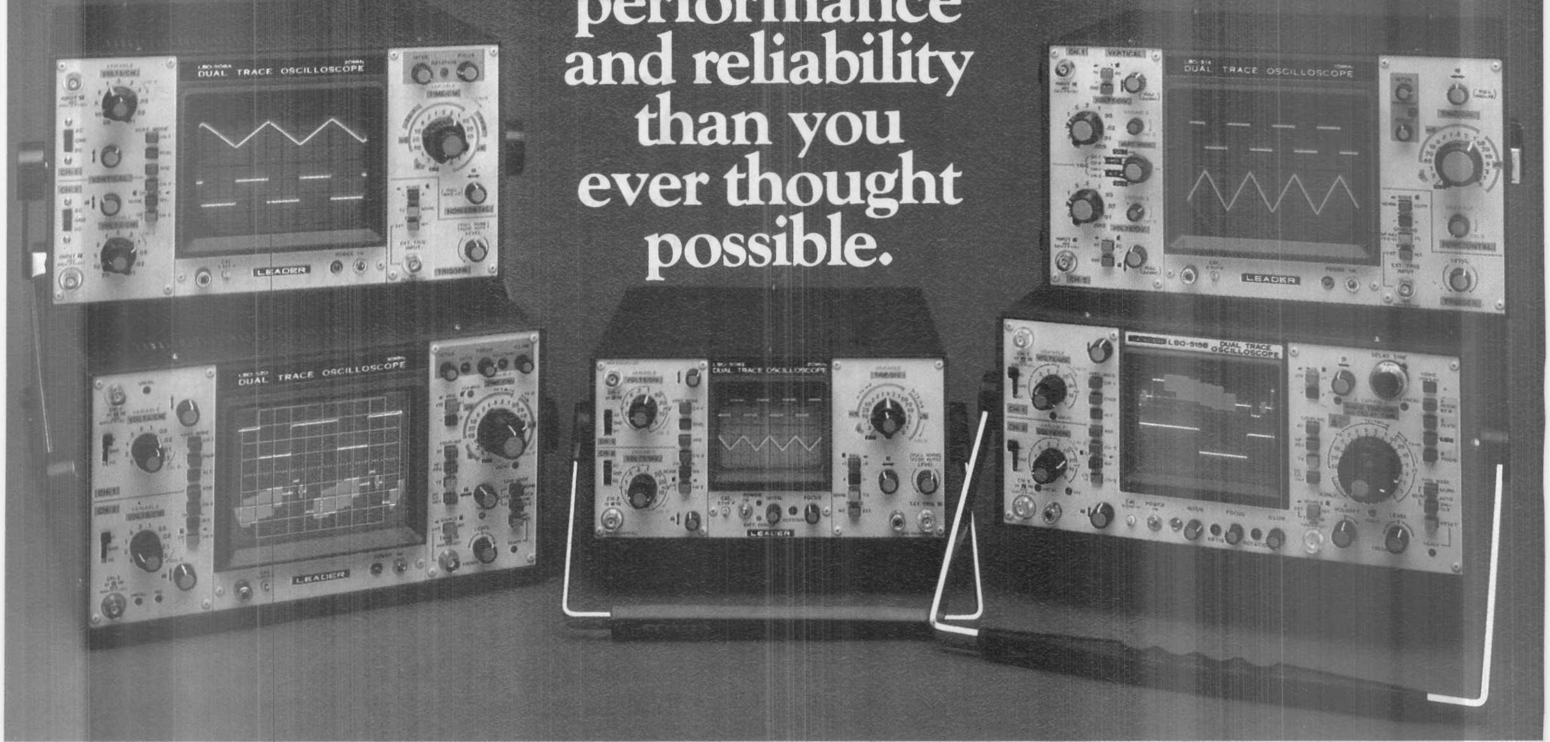


The surprising leader.

It's easy to see why LEADER oscilloscopes are now specified more than ever. More performance and quality for less cost... with immediate deliveries from over 100 stocking distributors. They also come with the best two-year warranty in the industry... backed by efficient factory service depots on the East and West Coasts.

A full-range of reliable, medium bandwidth oscilloscopes.

LEADER's oscilloscope line includes 11 models, single and dual trace versions, for bench or field use. All models offer comprehensive triggering controls, TTL compatible Z-axis modulation, front panel trace alignment control and convenient, color-keyed front panel layout. Probes are furnished with every oscilloscope and options include probe pouches, carrying cases, front panel covers and rack mounting adapters.

30 MHz delayed sweep – $1,530.

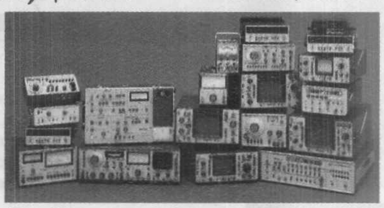
LBO-515B is a compact, precision oscilloscope at a moderate price. Using a PDA 4-inch CRT with parallax-free internal graticule, it features 5 mV sensitivity and delayed sweep for viewing and measuring complex waveforms. Also has 120 ns signal delay, trigger hold-off and x-y operation at full sensitivity.

30 MHz with signal delay – $1,100.

LBO-520 combines a 11.7 ns rise time with 5 mV sensitivity and 120 ns signal delay lines. Has single shot triggering, X10 sweep magnifier and bright, sharp PDA CRT. Triggers to 50 MHz.

20 MHz dual and single trace – $835., $610.

LBO-508A and LBO-507A give you versatility at low cost. Rise time is 17.5 ns with 1 MΩ (35 pFd) input impedance. Automatic or external triggering, X5 sweep magnifier, 10 mV/cm sensitivity and add/subtract modes.



Oscilloscopes, frequency counters, function generators, video and audio instruments... a LEADER instrument for almost every need.

10 MHz with 1 mV sensitivity – $645.

LBO-514 has both vertical and horizontal X5 magnifiers. Sensitivity is from 1 mV/cm to 10 V/cm. Sweep speeds from 0.2 s/cm to 0.1 μs/cm. Auto or normal triggering. Z-axis modulation. (Single trace version, LBO-513, $495.)

20 MHz battery/ac portable – $950.

LBO-308S provides lab performance and high reliability in field service applications. Sensitivity is 2 mV with a complete set of triggering controls and 18 sweep ranges to 0.1 μs/div. with X5 magnifier. Compact, lightweight with 3-inch rectangular, internal graticule CRT. (Optional 2 hour internal battery pack is recharged during ac operation, $75.00.)

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A history of high reliability permits LEADER to provide a generous 2-year warranty... backed by factory service depots on the East and West Coasts. A free, trial use of LEADER instruments is available to all qualified companies.

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- the name of your nearest "Select" distributor
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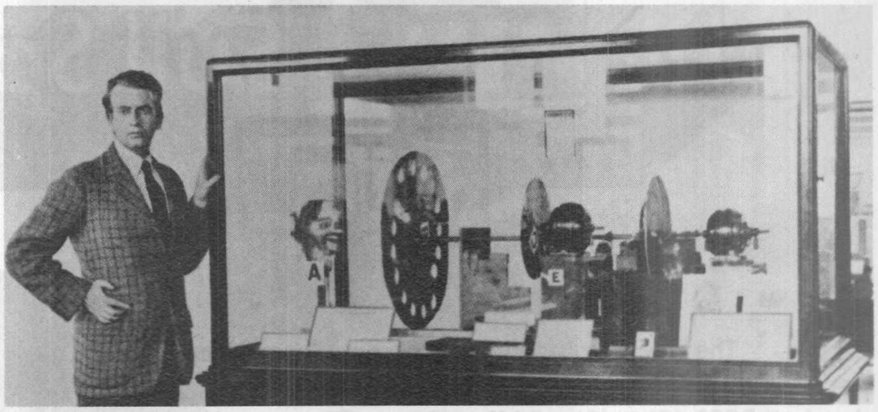
For Product Literature circle 74

For Product Demonstration circle 191

Paul Nipkow. His disk is the basis of just about all mechanically scanned television.



John Logie Baird. The first man to demonstrate (among other things) color television, stereo TV, and big-screen TV, stands beside his original 1926 apparatus.

behind the image region collected the sequential light samples and focused them on a single selenium cell. The cell would then produce a succession of currents, each proportional to the intensity of the light on a different element of the image.

At the receiving end, Nipkow proposed using a magneto-optic (Faraday-effect) light modulator to vary the intensity of the reconstructed image. To form the image, a second disk, identical to and rotating synchronously with the one at the transmitter, would be needed.

Nipkow built no hardware—which is probably just as well, because the technology of the time would not have permitted him to build his system; the light modulator alone would have required some 10 watts of control power. His disk, however, was a model for several later television systems that were built, most notably those of British inventor John Logie Baird.

Baird was apparently more interested in proving feasibility than in refining his ideas for commercial use. His feverish activity produced an incredible string of television firsts. Among them: transmission of TV pictures via telephone lines (London to Glasgow, 1927); telecast of 30-line pictures by shortwave radio across the Atlantic and to a ship at sea (the Berengaria, 1928); first demonstration of color TV (1928); stereo TV (1928); daylight TV (1928); regular TV service, including the transmission of synchronizing pulses (1929); simultaneous transmission of pictures and sound (1930); big-screen TV (1930); televising of a daytime public event (the Epsom Derby, 1931); televising of a motion-picture film (1931); and uhf transmission (1932).

All of this was done with variations on the Nipkow disk and the work constitutes the high-water mark of mechanically scanned television. Television as we know it today is, of course, all electronic and has a different genealogy.

The first all-electronic television system was described by Alan Archibald Campbell-Swinton in a letter to Nature magazine on June 18, 1908. Like Nipkow, Campbell-Swinton built no hardware but described his ideas in great detail. His system was based on the cathode-ray tube invented in 1897 by Karl Ferdinand Braun, in Strassburg. Campbell-Swinton proposed using CRTs as both the transmitter and receiver, recognizing that a key problem was "in devising an efficient transmitter which, under the influence of light and shade, shall sufficiently vary the transmitted electric current so as to produce the necessary alterations in the intensity of the cathode beam of the receiver."

One step closer to reality was Boris Rosing of the Technological Institute of St. Petersburg University in Russia, who in 1907 developed a TV system that used mechanical scanning on the transmitting end and the Braun CRT as a receiver. The Bolshevik Revolution ended his work, but it motivated one of his students, Vladimir K. Zworykin, to emigrate to the United States where, first at Westinghouse and later at the Radio Corp. of America, he helped develop television as we know it today.

Zworykin's most critical invention was the first iconoscope camera tube, which he patented in 1923. The key to its success was the fact that its silvered-mica photocathodes stored the charges induced by the image that was focused on them until the scanning electron beam simultaneously neutralized the charges and modulated itself. Approaches that lacked this storage feature, such as Philo Farnsworth's image dissector, were less successful.

A year after he invented the iconoscope, Zworykin invented the kinescope—a TV picture tube—thus becoming responsible for both the key transmitting and receiving elements of electronic television.

The broadcast television that followed two decades later would, of course, not have been possible without proper transmitters, receivers, modulators, demodulators, etc.—or, in other words, without proper radio. The world had been introduced to the potential of such a radio system as far back as 1906, when on Christmas Eve Prof. Reginald A. Fessenden of Harvard University made the first documented radio broadcast of speech and music. For this feat, he used a 50-kHz Alexanderson alternator, manufactured by the General Electric Co. Telegraph operators on ships crossing the North Atlantic were surprised on that historic night to hear music coming out of earphones that previously had emitted nothing but dots and dashes. Fessenden modulated the alternator's 1-kW output simply by putting a microphone in series with the antenna of his experimental station at Brant Rock, Mass. It is likely, but not certain, that the microphone was water-cooled.

In 1915, John R. Carson of American Telephone &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Vladimir Kosma Zworykin. If anyone deserves to be called the father of television that man is Zworykin, who, while working at Westinghouse, in 1923 invented the iconoscope camera tube (top right). The next year he invented the kinescope picture tube.

Telegraph invented single-sideband modulation, which saved both power and bandwidth in wire and wireless transmission. The invention resulted from a mathematical analysis of the nature of modulated carriers. Thus SSB is important not only in its own right, but as an example of the power of mathematical analysis.

Carson was also at the center of another episode involving mathematical analysis, but this showed its limitations. In 1922 he published a paper in which he proved mathematically that frequency modulation was useless for conserving bandwidth. That deduction was correct but Carson interpreted his mathematics to mean that "this type of modulation inherently distorts without any compensation advantages whatever." He concluded in a later paper (1928) that "noise, like the poor, will always be with us."

Along came Armstrong, who trusted his instincts more than Carson's mathematics and went on to invent fm. The flaw in Carson's mathematics was not in the elegant calculations; it was in his solving the wrong problem. Carson proved, quite correctly, that narrow-band fm was useless. Armstrong invented wide-band fm.

During World War I Armstrong, then a Signal Corps captain stationed in France, conceived and built the first superheterodyne receiver. He filed for a U. S. patent from Paris on Dec. 30, 1918, and received the patent on June 8, 1920. The superheterodyne circuit, the basis of just about every radio, television, and radar set in the world today, probably ranks as Armstrong's greatest achievement. Reduced to its fundamentals, it uses a local oscillator that beats down rf signals to a fixed intermediate frequency, where they may be amplified. The superhet also provides excellent selectivity and low noise, although Armstrong's reason for developing it seems to have been simply to find a way of amplifying radio waves at frequencies that were too high for vacuum tubes of the day to handle.

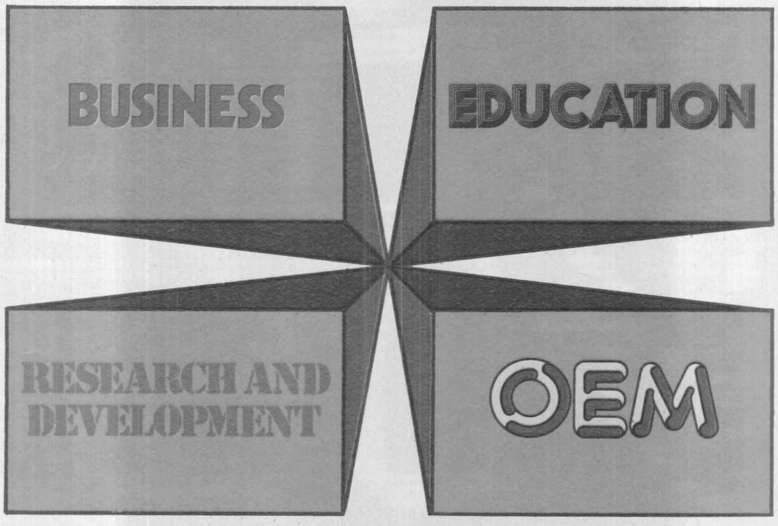
With the advent of the superhet, radio was here to stay. Its growth was phenomenal: sales of sets went from \$60 million in 1922 to \$900 million in 1929. In the process the electronics industry got the one element that made it a genuine part of modern American life: Government regulation.

Actually there had been a Radio Act of 1912, but the courts had held that it did not give the Government the power to assign wavelengths. So in 1927 Congress passed a new Radio Act establishing a five-member Federal Radio Commission with authority over licensing, frequency allocation, and power regulation.

The Federal Communications Commission came later, but that part of the story belongs to the 1930s.

OHIO SCIENTIFIC Professional Computers The Challenger Line

Ohio Scientific has been building microcomputers longer than any company currently in the personal computer and small business computer marketplace. The company features a uniquely broad line of computer systems and interchangeable accessories. Ohio Scientific computer models range from the $279 Superboard II which is the lowest cost complete computer on the market to the world's most powerful microcomputer; the C3-B GT which features a 74 million byte, 10 millisecond access disk and a 300 nanosecond instruction cycle processor. Ohio Scientific computer products are sold and supported by a world-wide network of over 350 computer dealers. The product line featured in this brochure is Ohio Scientific's professional series computers, software and accessories. All machines in this brochure incorporate dual 8" floppy disk drives and utilize the OSI 48 line BUS architecture of modular interchangeable PC cards. This architecture allows easy servicing, modification and upgrading. All machines in this brochure have internal firmware for instant disk loading and diagnostic testing and come complete with connecting cables, operating manuals and OS-65D disk operating system with extended BASIC so they can be utilized immediately when delivered by connection to a standard RS-232 terminal.



Business

The most popular use of Ohio Scientific professional computers is in small business accounting. The minimum configuration of each computer has dual 8" floppies, 48K bytes of RAM and an RS-232 port making each computer usable in business applications as delivered. All Ohio Scientific machines can operate as single-user, stand alone computers, but by simply adding one PC board, they can also be used as intelligent terminals in a distributed processing network. Business software includes an advanced BASIC operating system; OS-65U which features end user operating ease and security as well as highly advanced file structures and communications protocols. OS-65U is unique in that programs written in this operating language are immediately upward compatible from single-user floppy systems to multi-user timeshare and/or distributed processing networks with hundreds of megabytes of hard disk. Specific business applications software include a complete word processor for use on any professional series computer (WP-2), a family of conventional fully integrated accounting systems (OS-AMCAP) and a highly advanced data base manager and information management system (OS-DMS). DMS based applications modules range from simple general accounting packages to Construction Quotation, Medical and Legal billing systems in stand alone and/or integrated single-user, multi-user and network compatible configurations. The data base structure of these packages allows a high degree of end user customization without programming through use of powerful general purpose report writers, mathematical packages and an on-line query facility.

Education

Ohio Scientific personal computers are very popular in general education. The professional series offers capabilities for advanced educational use. Ohio Scientific's C1P and C4P series computers can be connected to a C2 or C3 computer to utilize its floppy disk and printer, and to allow teacher monitoring and communications under OS-65U Level 1 operating system.

The Challenger III's unique three-processor architecture provides opportunities for students to compare architecture, machine code, assemblers and upper level languages for three types of processors on one machine. OS-CP/M further provides a wide range of language capabilities including BASIC, FORTRAN, COBOL, PASCAL, APL, FORTH, ALGOL and others. Ohio Scientific's broad range of compatible accessories include a solderless interface prototyping board, a high speed analog I/O module and a PROM blaster for use in hardware labs. OSI's home security and control I/O, unique voice I/O, and new telephone interface coupled with the fast access high capacity CD-74 hard disk provide unique opportunities for advanced computer science investigations on an educational budget.

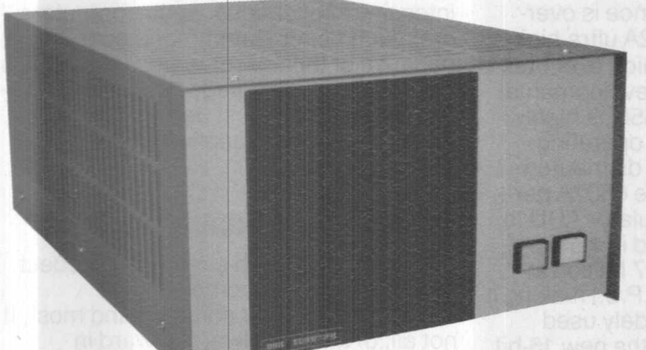
Research and Development

The C2 and C3 series computers feature the most advanced 6500 family operating system and architecture complemented by a fast resident interactive assembler/editor, on-line debugger and optional PROM blaster capability. The C3 extends this development system capabilities to the 6800 and Z80 family by nature of its three-processor architecture. Ohio Scientific's broad range of plug compatible accessories include a unique voice recognition breadboard, a powerful Votrax® based voice output system, a general purpose telephone interface, a fast analog I/O module, very fast high storage capacity hard disks, and computer network capabilities. These leading edge technology products provide opportunities for advanced architectural investigations and development without extensive hardware modifications. To further enhance the C3's usefulness in R/D applications, the company is currently developing a 68000/Z8000 CPU expander board which is designed to plug-in to existing C3 series computer systems.

OEM

Ohio Scientific's broad line of plug-compatible products and mass production economies provide a tremendous cost/performance benefit to both original equipment manufacturers and "systems houses".

Contact your local dealer or the factory for OEM contract details on computers, accessories, complete systems and/or subassemblies.



Ohio Scientific's new C2-OEM is designed to be the cost effective solution to business and industrial applications which can effectively utilize typical microcomputer execution speed. The C2-OEM benefits from Ohio Scientific's years of volume microcomputer production experience yielding an extremely competitively priced medium performance microcomputer.

The C2-OEM utilizes the popular 6502 microprocessor operated at 1MHz clock speed in conjunction with 48K or 450 NS Dynamic RAM memory.

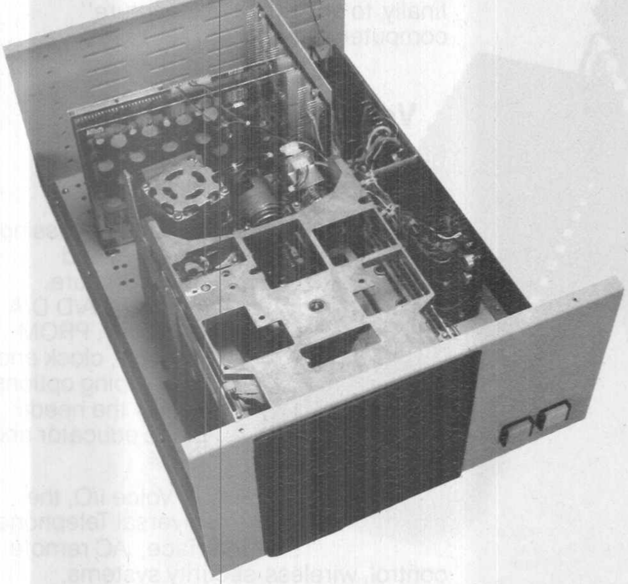
This hardware configuration when used in conjunction with Ohio Scientific's ultra fast BASIC by Microsoft yields Business environment performance equal to or better than competitive microcomputer systems.

The C2-OEM is housed in a versatile table top cabinet which can also be rack mounted or incorporated in a matching desk which also accommodates a CRT terminal and printer.

The system features very simple physical construction and the use of industry standard parts for reliable operation and simple servicing. All circuitry is on two 8 x 10″ OSI BUS compatible PC cards, one for the 48K memory and the other which contains the CPU, Firmware, RS-232 port and floppy controller.

The cards are plugged into an 8 slot back plane which provides tremendous expansion capability. The unit features two industry standard 8″ Floppy disk drives and is powered by two standard UL recognized open frame power supplies.

The C2-OEM's low cost, simple construction, standard performance, and factory configuration make it the logical choice when a simple, rugged "no problems" computer is desired.



The C2-OEM with cover off showing the placement of floppy drives, UL recognized power supplies and 8-slot OSI 48 BUS backplane.

Features:

Simplest, most cost-effective computer when typical microcomputer execution speed is acceptable.

- Full business configuration standard • 48K dynamic RAM
- .35 MIPS 6502 CPU • RS-232 port at 300 to 19,200 baud
- Dual 8″ floppies store 600 Kbytes
- OSI BUS oriented for modular expansion
- Fast low overhead disk operating system standard
- Microsoft BASIC with random and sequential access files
- Instant load disk bootstrap and front panel emulator in ROM

Prices

C2-OEM	As specified above	**$2799**

Options

-01	Double-sided disks doubles capacity to 1.2 Mbythes.	**800**
-02	Internal video board and keyboard with numeric pad provide complete terminal function with upper/lower case and graphics within the computer (a low cost alternative to conventional CRT terminals). Just add a TV monitor for a complete low cost system.	**299**
-03	Conversion to static RAM uses one more slot (2-24K boards) and adds 4.5 amps additional power.	**600**
-04	Double cases—uses separate cases for computer and floppies. Identical in appearance to the C3-S1.	**200**
-05	OS-AMCAP package provides AMCAP V1.5 and OS-65U at a $300 savings when purchased with the computer.	**$875**

Notable Accessories

AC-3P	12″ TV monitor for use with the 02 option	**129**
CA-17	Plug-in board adds intelligent terminal capability under Level 3 NET.	**298**
DSK-5A	5 foot matching desk with slide-in mounting for C2-OEM, C3-OEM or C2-NET.	**300**

Custom Desk DSK-5A

Special System

C2-NET	C2-OEM-04 with a CA-17 but without the floppy disk drives. Unit has special "down load" bootstrap ROM which loads the operating system from a network data base on power up. Just add on RS-232 terminal for the lowest cost intelligent terminal configuration.	**$1499**

Ohio Scientific Microcomputers for all reasons

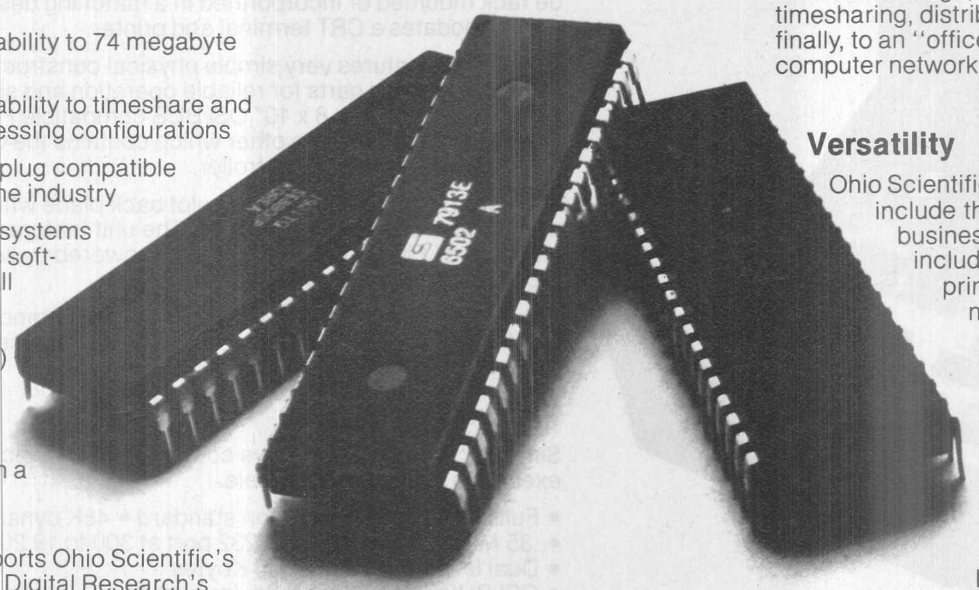
The Premium Performance C3 Series

The Challenger III family of computers is one of the most popular small computers in existence with tens of thousands of units installed to date. The C3 series provides several unique features including:

- 3 processors — the 6502A, 68B00 and Z80A
- User programmable interrupt vectors on all three processors
- OSI 48 line BUS architecture with 16 data lines and 20 address bits (1024K address space)
- Upward expandability to 74 megabyte disk drives
- Upward expandability to timeshare and distributed processing configurations
- Broadest line of plug compatible accessories in the industry
- Broadest line of systems and applications software of any small computer (three processors is unbeatable here)
- Fastest instruction execution speed commercially available in a microcomputer (with GT option)

The C3's Z80 supports Ohio Scientific's implementation of Digital Research's CP/M® operating system. This very popular operating system supports nearly a dozen upper level languages and hundreds of business, scientific and educational packages from several independent suppliers. The Challenger III's 4MHz Z80A processor, fast stepping rate floppies and large disk buffer size make it one of the fastest CP/M operating system compatible computers available.

CP/M's excellent performance is overshadowed by the C3's 6502A ultra-high performance processor which executes Ohio Scientific's OS-65D developmental operating system and OS-65U, a highly advanced business BASIC operating system with multi-user and distributed processing capabilities. The 6502A performs a memory to accumulator ADD in 1.0 μs. and a jump extended in 1.5 μs. with an overall average of .7 Million Instructions per Second (M.I.P.S.) making it far faster than any other widely used microprocessor (including the new 16-bit versions).



The GT option further extends Challenger III performance by utilizing the 6502C processor and high speed static RAM (150 ns. access) to achieve memory to accumulator ADD of 600 ns. and 1.2 MIPS average operation. This performance level places the C3 GT models comparable to mid-range minicomputers ($50,000 to $100,000 price range) in typical business and other information intensive applications. Such computers are much faster in arithmatic operations because of their wider wordwidth but this performance advantage is not cost effective in all but the most demanding number crunching applications.

Upward Expandability

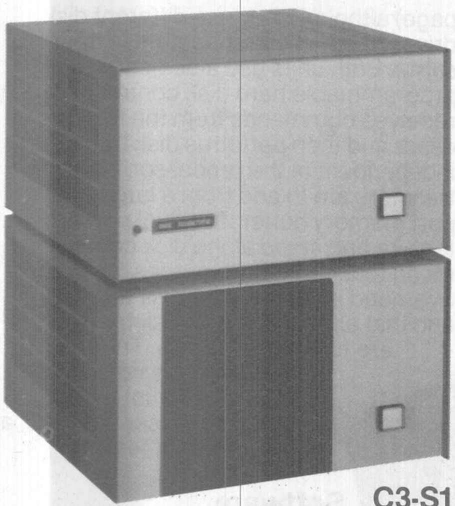
Users can start with a relatively modest C3-OEM table-top computer and transport all of their software and most, if not all, of their hardware upward in simple plug-together expansion steps to hard disk storage, multi-programming — timesharing, distributed processing and finally, to an "office of the future" computer network.

Versatility

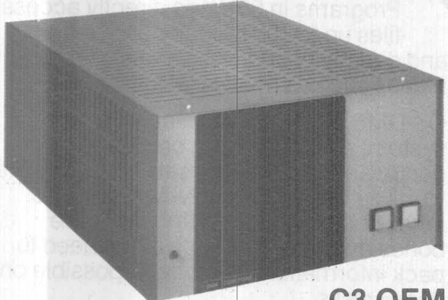
Ohio Scientific's plug-in options include the full scope of business accessories including a word processing printer, modem and matching furniture. Parallel I/O, A/D D/A capability, PROM blaster, clock and prototyping options satisfy the needs of the educator and OEM.

Voice I/O, the Universal Telephone Interface, AC remote control, wireless security systems, affordable ultra-fast execution speed, network capability and huge storage capacity challenge the most creative innovators to develop the applications of tomorrow.

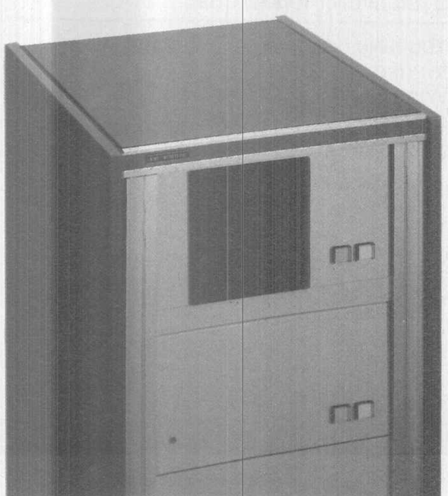
The Challenger III Series



C3-S1



C3-OEM



C3-A

Family Features

Premium performance 3-processor computer systems.

- Full business configuration standard
- 3-processors 6502A, 68B00, Z80A
- 6502A operation at .7 MIPS standard
- Z80A operation 4MHz, 68B00 operation 2MHz
- 48K high speed static RAM standard
- 20 address bits with memory pager addresses 768K
- User programmable interrupt vectors
- 8-bit parallel I/O port
- Instant loading floppy disk bootstrap/hard disk bootstrap/front panel emulator in ROM
- RS-232 port strappable from 300 to 19,200 baud
- Dual 8″ floppies store 600K bytes
- OSI 48 line BUS oriented for modular expansion
- OS-65D fast low overhead development operating system with ultra-fast BASIC standard
- OS-65U advanced business operating system standard
- Largest accessory family in the microcomputer industry
- Largest software library in microcomputing (due to its unique 3-processor architecture)

C3-S1, C3-OEM

These two computers are table-top versions of the C3 system with a total of eight OSI BUS slots. They are ideally suited to applications which do not require hard disk drives and/or multiple users. Both systems can be enhanced by adding the GT option and/or dual-sided drives. They support OS-CP/M by expansion to 56K RAM and can be networked by expansion to 56K and a network I/O port. (The CA-17 provides network and CP/M compatibility.) The C3-OEM is a single-case table-top unit similar to the C2-OEM except for larger power supplies and can be mounted in the DSK-5A. The C3-S1 is in two cases which can be shipped via U.P.S. (the C3-OEM must be shipped by freight). The C3-S1's floppies can be independently turned off; a useful feature for process control and security applications.

Prices

C3-S1	As specified above with 48K	**$4095**
C3-OEM	As specified above with 48K	**3995**
-GT Option	Increases 6502 execution speed to 1.2 MIPS average (150 ns main memory)	**1500**

C3-A

The C3-A system is a 17-slot version of the C3 series in a stylish free-standing equipment rack. Although the standard machine has the same circuit boards and hence the same functional specifications as the C3-OEM or C3-S1, the system can be directly expanded to 8 users, hard disk operation and a network data base node configuration by simple plug-in operations. The rack also accommodates the PDS-1 system power sequencer and Alloy Engineering cartridge tape back-up units.

The C3-A features rack slide-mounted CPU and floppies as well as removable side panels and locking back door for convenient servicing and upgrading.

Prices

C3-A	As specified above with 48K	**$5995**
-GT Option	Increases 6502 execution speed to 1.2 MIPS average (150 ns main memory) and adds heavy duty switching power supplies.	**1950**

C3 Family Options

-01	Double-sided drives, doubles capacity to 1.2 Mbytes	**$800**
-06	OS-AMCAP package provides AMCAP 1.5 at a $200 savings when purchased with the computer (65U is standard with C3's)	**775**
-07	CP/M package requires CM-10 or CA-17 for operation. Provides OS-CP/M, Z80 Assembler/Editor, Microsoft Z80 BASIC, FORTRAN and COBOL at a $250 savings over individual prices when purchased with the computer.	**400**
-08	Real time clock option	**100**

Winchester Technology Disks

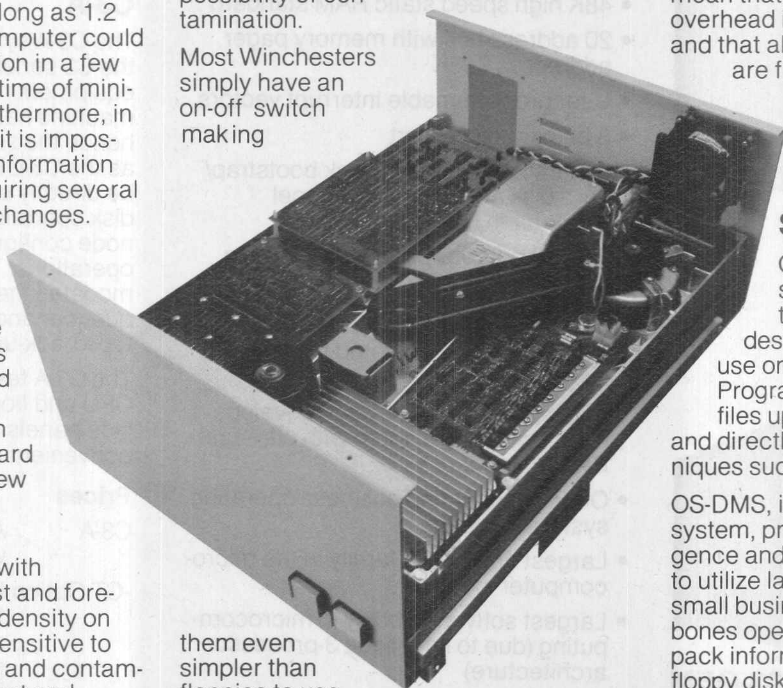
Floppy disks store from 250K bytes to 500K bytes per surface in a series of concentric circles called tracks which each store 2.5K to 7K bytes. To access specific information a head must be mechanically positioned over the track, then the computer must wait for the information to rotate under the head. On an 8″ floppy accessing a specific piece of information this can take as long as 1.2 seconds even though the computer could have processed the informaion in a few microseconds. (The access time of mini-floppies is much worse.) Furthermore, in most business applications, it is impossible to store all necessary information on one floppy disk; thus requiring several diskettes and frequent disk changes.

The traditional solution to these problems is the conventional removable platter hard disk. These disks rotate ten times faster than floppies and use more elaborate head positioners to move from track to track as much as ten times faster than floppies. Hard disk storage ranges from a few megabytes to a few hundred megabytes.

There are several problems with conventional hard disks. First and foremost, the extremely high bit density on the disks makes them very sensitive to mechanical misadjustments and contamination such as vibrations, dust and temperature differences of a few degrees, etc. Attempts to use removable hard disks in any other than a big computer, air conditioned, clean room environment by other than experienced computer operators can result in expensive head crashes and the complete loss of a disk pack. The second problem with these drives is that since they require close mechanical tolerances for bit density, disk removability and interchangeability, they are very complex mechanical devices. This results in large physical size, high power requirements and, most of all, high initial cost and high maintenance cost.

Enter the Winchester:

In the mid-70's a new disk technology was developed which eliminates most of the undesirable features of hard disks for small computer users; the Winchester hard disk. Winchesters utilize fast rotating high density disks and medium to high speed head positioners to achieve performance comparable to the most expensive hard disks. However, to minimize mechanical complexity and difficulty of use, they use fixed or non-removable media. Because the media is factory installed, the critical head-disk tolerances can be maintained with relatively simple mechanics. The fixed nature of the drive allows the disk chamber to be sealed eliminating the possibility of contamination.



Most Winchesters simply have an on-off switch making them even simpler than floppies to use from an operator viewpoint. In high storage capacity models they achieve the lowest cost per bit of any Random Access Memory technology now available.

The Winchester disk solves all the problems of floppies and conventional hard disks but creates one big new one! Back Up. Ohio Scientific has effectively solved this problem with three approaches depending on the specific application, see the box below.

Ohio Scientific Winchesters

OSI pioneered the use of Winchesters with microcomputers in 1977. Since then, we have installed more units than anyone else and have developed the most sophisticated Winchester hardware and software products for microcomputer use.

Hardware

Ohio Scientific offers two Winchester disks; the CD-23 and CD-74 (see next page) although they use different disk drives, the basic architecture is the same. Both units use a dedicated but programmable hard disk controller which receives commands from the host processor and then performs disk transfers independent of the processor. Data transfers are to and from a large dual port memory buffer. The dual port architecture and stand alone disk controller mean that virtually no processor overhead is required for disk transfers and that all segments of disk transfers are fully interruptable. Thus, disk operation does not degrade terminal interrupt response time in multi-user systems, a very important feature.

Software

OS-65U business operating systems and OS-DMS information management systems were designed from the "ground up" for use on Winchester based computers. Programs in 65U can directly access files up to 100 megabytes in length and directly support fast access techniques such as multi-key ISAM.

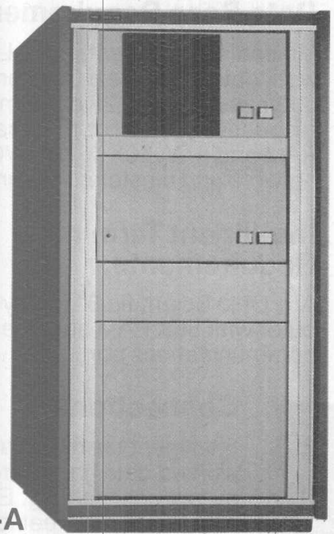
OS-DMS, information management system, provides a high degree of intelligence and end user versatility by its ability to utilize large disk files whereas most small business computers offer bare bones operation because of the need to pack information as tightly as possible on floppy disks.

Ohio Scientific Winchester disk based computer offer business users a dramatic improvement in total performance over floppy based micro and minicomputers at a relatively modest cost.

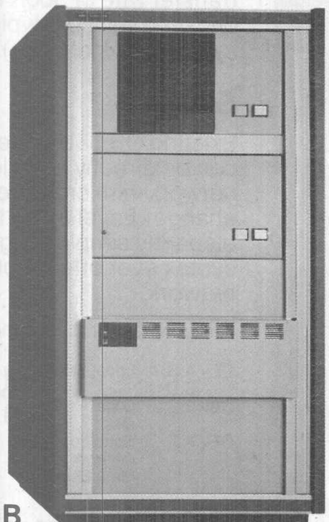
You now have three backup options for use with the C3-B and C3-C Winchester disk based computers:

1. Fast floppy dumper under OS-HDM for small files (5 Mbytes or less). Daily to weekly backup.
2. 3M tape backup unit from Alloy Engineering. About 11 Mbytes per tape, cost about $3500. For medium files (Under 11 Mbytes). Weekly backup.
3. Networked C3-B's and/or C3-C's. Ultrafast backup of files up to disk capacity for Large files (over 11 Mbytes) and/or frequent backup requirements.

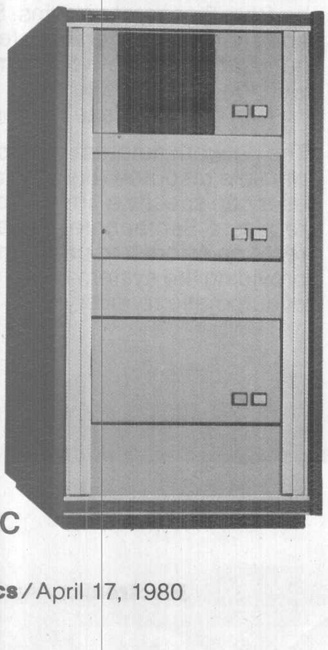
(Prices and specs subject to change without notice)



C3-A



C3-B



C3-C

Family Features

All standard C3 features including:

- 3-processor CPU
- .7 MIPS 6502A
- 48K static RAM
- Dual 8″ floppies
- Free standing rack for direct expansion capabilities
- 17-slot OSI 48 line BUS architecture for large system expansion
- Directly accepts up to 8 users with currently available memory boards, more with higher density boards in the future
- Directly expandable for use as Network data bases
- Slide-mounted subassemblies, removable side panels and locking rear door for easy expansions and service

C3-A

The floppy only rack based C3 for users who anticipate expansion to hard disk, multi-user and/or networking in the future. Additional specs are on the preceding pages.

C3-A	**$5995**
CD-74 expands C3-A to C3-B	**7500**
CD-23 expands C3-A to C3-C	**4500**
CA-16 heavy duty cooling pack (specify B or C)	**150**

C3-B

The world's most powerful microcomputer (when GT equipped). Features the highly advanced and extensively field proven OKIDATA 3306 Winchester disk. Some 3306 drives have operated since 1977 without a single failure.

Features

- System boots from floppies or hard disk on power up
- 74 megabytes end user workspace under OS-65U, 80 megabytes unformatted
- Ultra-high performance disk

  74 millisec worst case access
  38 millisec average

  10 millisec access on cylinder (215K user workspace)

  8 megabits per second transfer rate
- Simple on/off disk operation with elaborate internal protection from improper temperature, line voltage and controller failures
- Features spindle brake and designated head landing areas for much longer operational life than the newer low-cost Winchesters
- Highly advanced OS-65U operating system:

  Multiple level pass word security

  Multiple operating systems on disk

  Ultra-high speed "FIND" command for high speed string searches (Associative Access)

  Upward compatible with multi-user and network systems with full file, peripheral and communications arbitration between users
- Expandable to CP/M operation by adding 4K (CM-2 memory)
- Available factory configured for up to 8 users and network data base operation
- Comes standard with real time clock and heavy duty cooling package

C3-B	**$12,995**
GT Option (as per C3-A) add	**1,950**

C3-C

A medium performance Winchester disk based system which provides the ideal cost/performance ratio in typical small business applications. The C3-C uses the Shugart SA4008 29 megabyte Winchester disk.

Performance specifications, hardware configuration and software is identical to the C3-B with the following exceptions:

- 23 megabytes of end user workspace under OS-65U
- 29 megabytes unformatted capacity
- Medium performance Winchester

  240 millisec worst case access

  87 millisec average access

  10 millisec access on cylinder (110K user workspace)
- Simple on/off disk operation

C3-C	**$9,995**
GT Option (as per C3-A) add	**1,950**

Ohio Scientific Microcomputers for all reasons

Multiple User Systems

In applications where several terminals are desired, but most of which will be utilized for entry and editing (such as order entry systems), multiple user microcomputers are feasible. In environments where it is commonplace for more than one user to be processing information at a time, a single microcomputer may become annoyingly slow. A better configuration for such applications is distributed processing as discussed later.

All C3 series computers will support up to 16 timeshare users under OS-65U Level 3 providing that the computer has a real time clock, sufficient memory and the appropriate communications ports.

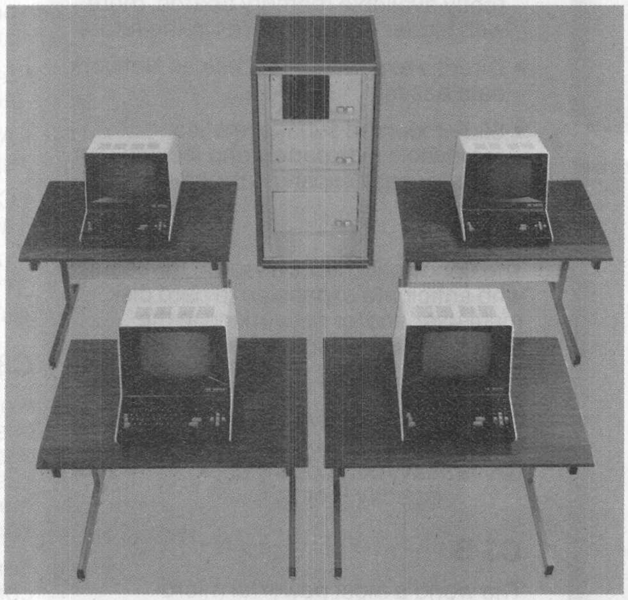
C3 computers utilize bank switching for multiple users. Each user must have 32K to 48K RAM and an RS-232 port. The host machine must also have 4K RAM for the multi-tasking executive. The computer timeshares individuals by interrupting a user after a set time (approximately 100 milliseconds) and bank switches to the next user in a "round robin" fashion. Bank switching architecture is not as memory efficient as techniques which use re-entrant code or swapping disks but is by far the fastest technique, requiring only a few microseconds of processor overhead per switch, a feature which is most important in multiple user systems.

Although OS-65U Level 3 will support timesharing on any C3, it is only recommended on C3-B and C3-C computers. This is because of the desirability of 17 BUS slots for multiple user memory partitions and the dramatic performance advantages of Winchester disks over floppies.

Networking

In a distributed processing system using OSI microcomputers as intelligent terminals (local systems) most of the work load is handled locally. Overall system performance does not degrade under heavy job loads. Each local system performs entry, editing and execution while utilizing a central data base for disk storage, printer output, and other shared resources.

For more demanding applications it is desirable to have several data bases, each with its own collection of local systems. Such an inter-connected set of data bases is called a network. Each data base and its local intelligent and dumb terminals is called a cluster.



Level 3 NET

OS-65U Level 3 NET supports this advanced networking and distributed processing capability as well as conventional single user operation and timesharing. Level 3 NET supports local clusters of intelligent microcomputer systems as well as dumb terminals for the purpose of utilizing a central Winchester disk data base and other shared resources. The system also has full communications capability with other Level 3 data bases providing full network capability.

Level 3 resides in each network data base. A subset system resides in each intelligent terminal. Each data base supports up to 16 intelligent systems and up to 16 dumb terminals. Level 3 also supports a real time clock, printer management, and other shared peripherals.

Data Base Requirements

Minimal requirements for a Level 3 network data base are a C3-C or C3-B computer system with 23 or 74 megabytes respectively, console terminal, 88K bytes RAM and a CA-10X 16 port I/O board for network and cluster communications.

Intelligent Terminal Requirements

Any Ohio Scientific 8″ floppy based computer with 56K RAM and one data base communications port.

Connections

Intelligent terminals and networked data bases are connected by low-cost cabling. Each link can be up to 10,000 feet long at a transfer rate of 500K bits per second, and will cost typically 30¢ a foot (plus installation).

Syntax

Existing OS-65U based software can be directly installed on the network with only one statement change! Level 3 has the most elegantly simple programming syntax ever offered on a computer network.

File syntax is as follows:

DEV A,B, C,D	Local Floppies	unchanged from single user and timeshare system
DEV E	Local Hard disks	
DEV K-Z	Specific network Data Bases	

Each of up to 8 open files per user can be from 8 separate origins. Specific file and shared peripheral contentions are handled by 256 network semaphores with the syntax Waite N

Waite N, close

The network automatically prioritizes multiple resource requests and each user can specify a timeout on resource requests. Semaphores are automatically reset on errors and program completion providing the system with a high degree of automatic recovery.

Time Sharing/Networking

One Step at a Time

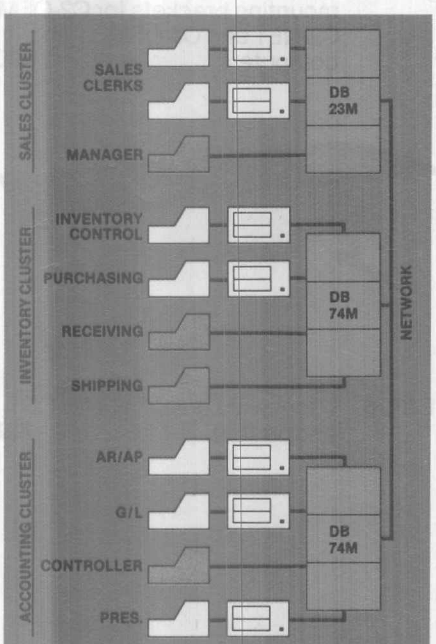
Best of all, Ohio Scientific users can develop distributed processing systems economically one step at a time. A user can start with a single user floppy system, add a hard disk, then timesharing, then a second Winchester data base for backup and, finally, cluster intelligent terminals to achieve a full network configuration.

Level 3 Support Group Factory Configured Systems

Prices include OS-65U Level 1 but do not include 65U Level 3 or Level 3 NET. Machines with NET prefix have the specified number of users plus NETWORK data base node capability. The NETWORK partition can be used as an extra user through its diagnostic RS-232 port.

For example, a 4-user system with networking can be used as a 5-user system without networking.

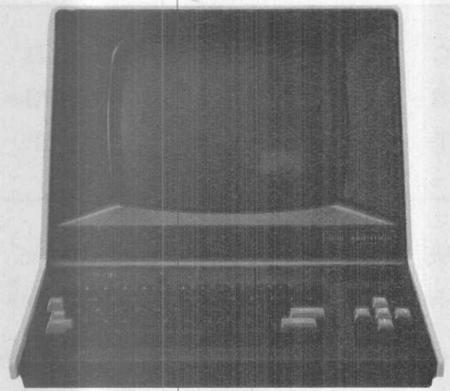
Network systems have ports for 4 intelligent terminals (cluster ports) and 1 NET port.



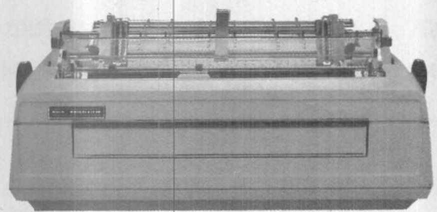
Time-share Users	C3-C .35 MIPS	C3-C .7 MIPS	C3-C .7 MIPS + NET	C3-B .35 MIPS	C3-B .7 MIPS	C3-B .7 MIPS + NET
1	NA	$9995 C3-C	$11,995 C3-C-N1	NA	$12,995 C3-B	$14,995 C3-B-N1
2	$10,900 C3-C-12	11,400 C3-C-22	12,995 C3-C-N2	$13,900 C3-B-12	14,400 C3-B-22	15,995 C3-B-N2
3	11,700 C3C-13	12,400 C3-C-33	13,995 C3-C-N3	14,700 C3-B-13	15,400 C3-B-33	16,995 C3-B-N3
4	12,400 C3-C-14	13,400 C3-C-44	15,200[1] C3-C-N4	15,400 C3-B-14	16,400 C3-B-44	18,200[1] C3-B-N4
5	13,100 C3-C-15	NA	NA	16,100 C3-B-15	NA	NA
6	13,800 C3-C-16	NA	NA	16,800 C3-B-16	NA	NA
7	14,500 C3-C-17	NA	NA	17,500 C3-B-17	NA	NA
8	15,200 C3-C-18	NA	NA	18,200 C3-B-18	NA	NA

Note 1. Uses 16-slots, 1 open, comes with printer and word processing ports installed.

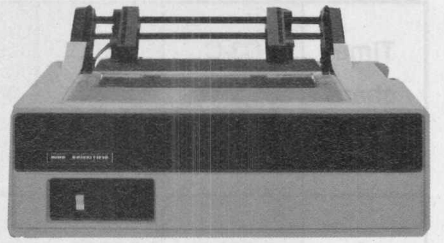
Ohio Scientific Accessories for all reasons



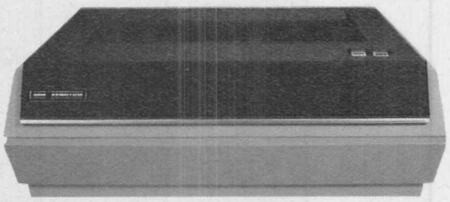
AC-7B
CRT terminal for use on all OSI single and multi-user systems. Features upper/lower case 24x80 character display, numeric keypad, dual intensity, protected fields, cursor addressing and much more. **$995**



AC-14
High performance word processing printer. Produces typewriter quality output at up to 55 characters per second. Features quick-change ribbon cartridges and drop-in print wheels for interchangeable fonts. Prints up to 132 columns, comes with friction-feed capability for stationary and adjustable width tractor-feed for computer forms. Complete with paper guides and silencer options. Produces proportional spaced characters when used with WP-2 word processor package. Comes complete with high speed parallel interface, cable and one print wheel. **$2795**



AC-9TP
A rugged moderate performance business printer. Impact printing at 110 characters per second, prints 80 or 132 columns across the page, has adjustable width tractors and forms stacker. Comes complete with parallel interface and connecting cable. **$1250**



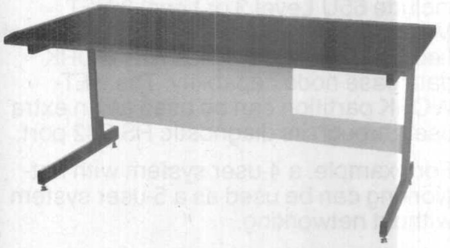
AC-5A
Deluxe business printer. This "Top of the line" shuttle printer very quietly prints an entire line at a time using dot matrix impact technology. The unit prints 160 lines per minute at a 132 character column width. Features upper and lower case, 12 *programmable* fonts, 11 program selectable form lengths and much more. Comes complete with adjustable width tractor-feed, high speed parallel interface and cable. **$2950**

AC-11P
300 baud modem for use with conventional telephone handsets. Features unique originate/answer back capability which allows two similarly equipped computers to talk to each other as well as communicating with timeshare services. Requires an RS-232 port for operation. **$199**

OSI Desks

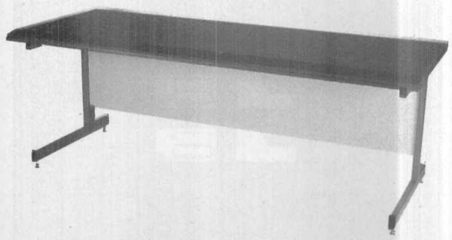
DSK-3 3 foot wide CRT and printer stand. **$175**

DSK-4 4 foot wide desk. **$215**



DSK-5 5 foot wide desk. **$250**

DSK-5A 5 foot desk with cutout and mounting brackets for C2-OEM, C2-NET and C3-OEM computers. **$300**



DSK-6 6 foot wide desk (best for CRT and printer). **$285**

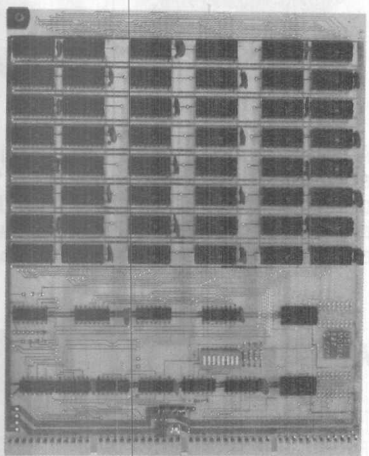
Microcomputer Components

OSI Power Sequencers Turn Entire Systems On/Off From One Keyswitch.

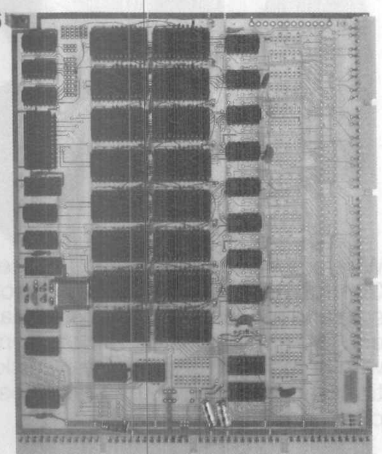
PDS-1 Switch panel for C3-A, B, C. Sequences CPU, floppies, hard disk, CRTs, printer and other accessories. **$350**

PDS-3 Switch panel for DKS-5A desk. Sequences CPU, floppies, CRT, printer and other accessories. **$200**

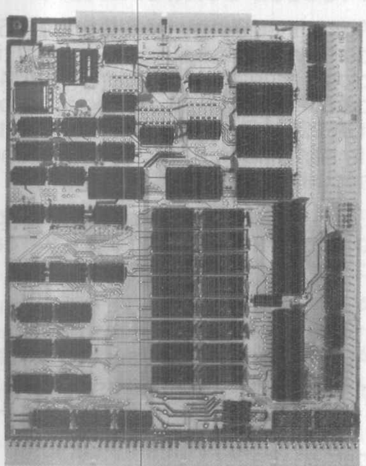
CM-9



CA-10-16



CA-18A



Memories

CM-2 4K 2MHz static for expanding C3-B, C3-C to 56K for CP/M and/or networking. **$129**

CM-3A 16K 2MHz low power static standard C3 memory. **$399**

CM-6 48K 1MHz dynamic for C2-OEM and some timeshare systems. **$549**

CM-9 24K 2MHz medium power statics usable in computer with booster supplies or high current switchers. **$450**

CM-10 8K 2MHz static for expanding C2 and C3 computers to networking or CP/M. (C3 only) **$198**

General I/O

CA-9 Centronics parallel printer interface with cable. **$175**

CA-10X 1 to 16 RS-232 port I/O board. 300-19200 baud plus synchronous operation at 250K and 500K baud. 1 port standard. **$125**
Each additional port. **$ 50**

CA-10-N5 CA-10X port board configured for four cluster communications ports and one network communications port all at 500K baud for use in data bases. **$349**

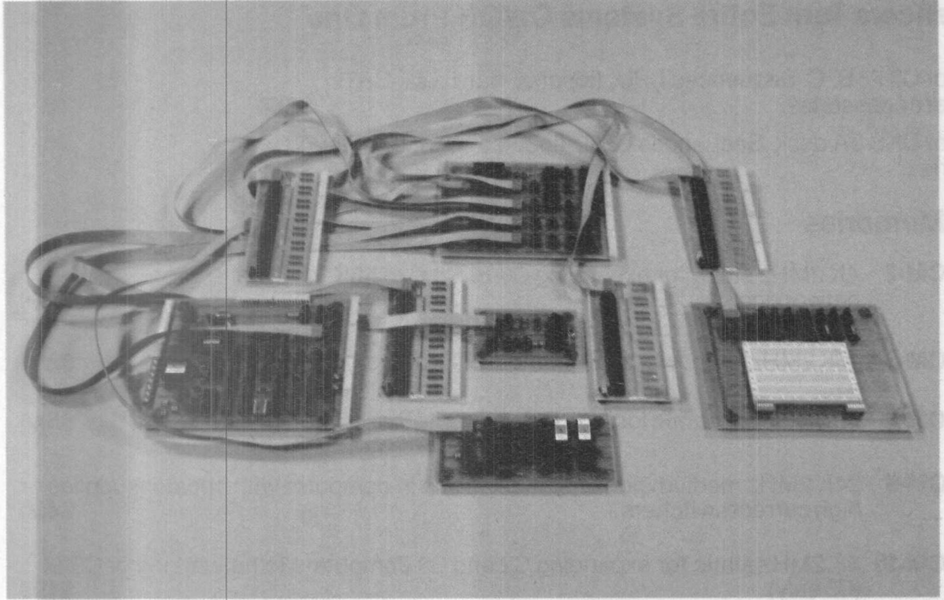
Combinational I/O

CA-17 8K 2MHz RAM and 1 cluster port plus 1 auxiliary RS-232 port. (Converts any C2 or C3 to networking.) **$298**

CA-18 1 Centronics parallel printer port with cable, 1 parallel word processing printer port with cable, 2 RS-232 ports and 1 cluster port. **$398**

CA-18A As above with 8K 2MHz RAM and 2 additional RS-232 ports (4 total), i.e., fully populated 555. **$598**

See the OEM and R/D section for more accessory boards.



Ohio Scientific's Revolutionary New 16 Pin I/O BUS

Modern technology has made it possible to pack far more I/O functions on a computer board than one can practically connect to. Ohio Scientific has solved this problem with a series of remote "head end cards" which feature tremendous I/O capability and connect to the computer via single inexpensive 16 pin DIP ribbon cables. Thus I/O connection can be made away from the computer's card cage.

CA-20
8-port I/O BUS interface and calendar clock provides interfaces for 8 head end cards and a battery back up clock with hours, minutes, seconds, 1/10 second, day, and date. The automatically recharged batteries will power the clock for months. **$175**

CA-20A
As above without clock **$95**

Head End Cards

CA-21
48 Line Parallel I/O card features 3 PIA's and prototyping area **$45**

CA-22
High speed analog I/O module. Two 12-bit D/A converters, 1 12-bit/8-bit A/D converter with 16 channel input multiplexer. Factory configured for ± 10V offset binary, user jumperable for other configurations. Max error ± 2 LSB. 28,000 12-bit conversions per second. 66,000 8-bit conversions per second, drift. -50 ppm per °C. Note, the CA-22 can also be directly plugged into the computer without a CA-20, thus occupying one slot. **$598**

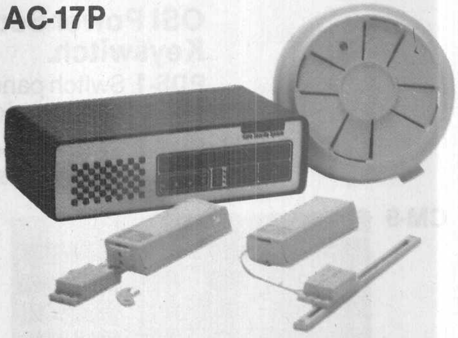
CA-23
PROM Blaster. Programs 2758, 2716, 2732 and 2764. 8 through 65K EPROMS. Programs and verifys from memory or other EPROM. **$195**

CA-24
Solderless interface prototyping board features a PIA and TTL I/O as well as provisions for direct user connection of devices such as the 6850 ACIA. Board also features 16 switches and 16 LED's. Has a large solderless breadboard for prototyping or educational lab exercises. **$175**

CA-25
Security and AC remote interface connects the AC-17P home security system and AC-12P wireless remote control system to C2 and C3 computers. **$45**

16 pin BUS family boards should be powered by external means where possible, however, a few modules can be supported by the host computer's supply if necessary.

AC-17P



A home security system, that's wireless and includes a control console, a fire detector, two window protection devices and one door unit. Additional protection devices are commercially available. **$249**

AC-12P

Wireless AC remote control. AC Remote Control Starter Set includes control console and modules to operate two lamps and two appliances via remote control with home control software on disk. Additional appliance and lamp modules are commercially available. **$175**

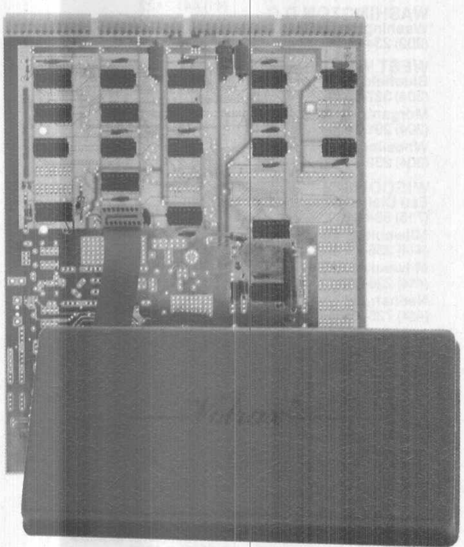
Process Control BASIC

A modified 9-digit BASIC under 65D with commands that support the real time clock, time of day clock (CA-20), 48 line parallel I/O (CA-21) analog I/O model (CA-22), AC remote (AC-12P) and to a limited extent the UTI (AC-15V) and security system (AC-17P). **$250**

Security BASIC — Use your computer for business accounting during the day and office and plant security at night!

A modified BASIC under 65D with commands which support the real time clock, AC-remote (AC-12P), security system (AC-17P) and universal telephone interface (AC-15V). Comes complete with a library of security program demonstrations. **$95**

OEM and R/D Accessories



CA-14A Votrax Voice I/O System

This Votrax Voice Synthesizer module has the capability of generating English speech phonetically. The supporting software simply feeds the phonetic spelling of English words to the module which generates medium quality spoken words. This advanced Votrax system is capable of generating all English phonemes as well as four levels of inflection on each phoneme. CA-14A also includes a voice recognition experimentation area which must be user populated. This experimentation board contains a five filter feature extractor with zero crossing detectors and envelope filters. The CA-14A in conjunction with the CA-22 high speed analog I/O module provide a complete voice recognition lab. **$399**

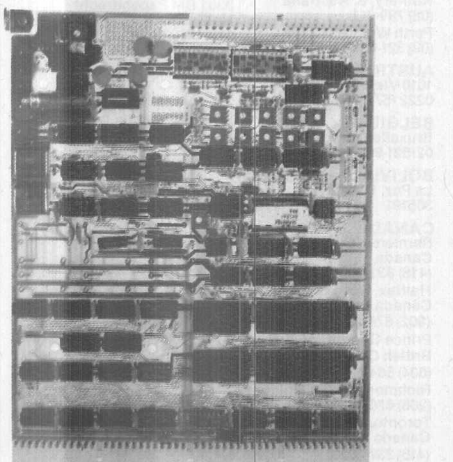
Voice Output Software

OS-Vocalizer I

"Generation by Rules System". Runs under OS-65D or OS-65U. Accepts conventional English spelling and outputs the phonetic spelling to the Votrax module in real time. Also, will print phonetic spellings for use by other programs. **$150**

OS-Vocalizer II

Runs in one partition of a 65U Level 3 system. Accepts normal print statements from other partitions (users) and vocalizes them in real time. Uses disk look up for the 3000 most common words and generation by rules for words not on file. End user can add approximately 1500 additional words to file. Generates the most legible speech now attainable via totally synthetic means (i.e. not recorded human speech). Operates on a C3-B or C3-C with at least two partitions. **$975**

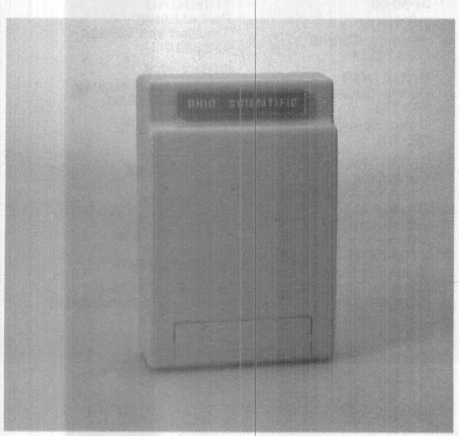


CA-15 Universal Telephone Interface

The Universal Telephone Interface provides the host computer with general purpose telephone communications capability. The board can answer and originate calls. It can communicate with internal 300 baud modem in originate or answer back mode. It can also communicate with touch-tone and decode touch-tone. The board also has multiplexers to route spoken voice out to external devices such as recorders, voice recognition circuits, A/D converters and can accept spoken voice from several sources to dispatch to the telephone. The UTI can be used with touch-tone or rotary dial lines via its pulse code dialer. When equipped with a Votrax module or used in conjunction with a CA-14 voice I/O, it can respond with computer generated English voice output. The UTI is connected to telephone lines via a CBT. CBT's can be rented along with the telephone lines from your local telephone company or can be purchased from your local dealer and connected in parallel with your existing telephone circuitry. **$499**

UTI with Votrax CA-15B

The Universal Telephone Interface as above with Votrax Voice module allows your computer to generate English speech phonetically. It also includes an audio amplifier to allow the Votrax module to be used stand alone independently of the telephone lines. **$799**



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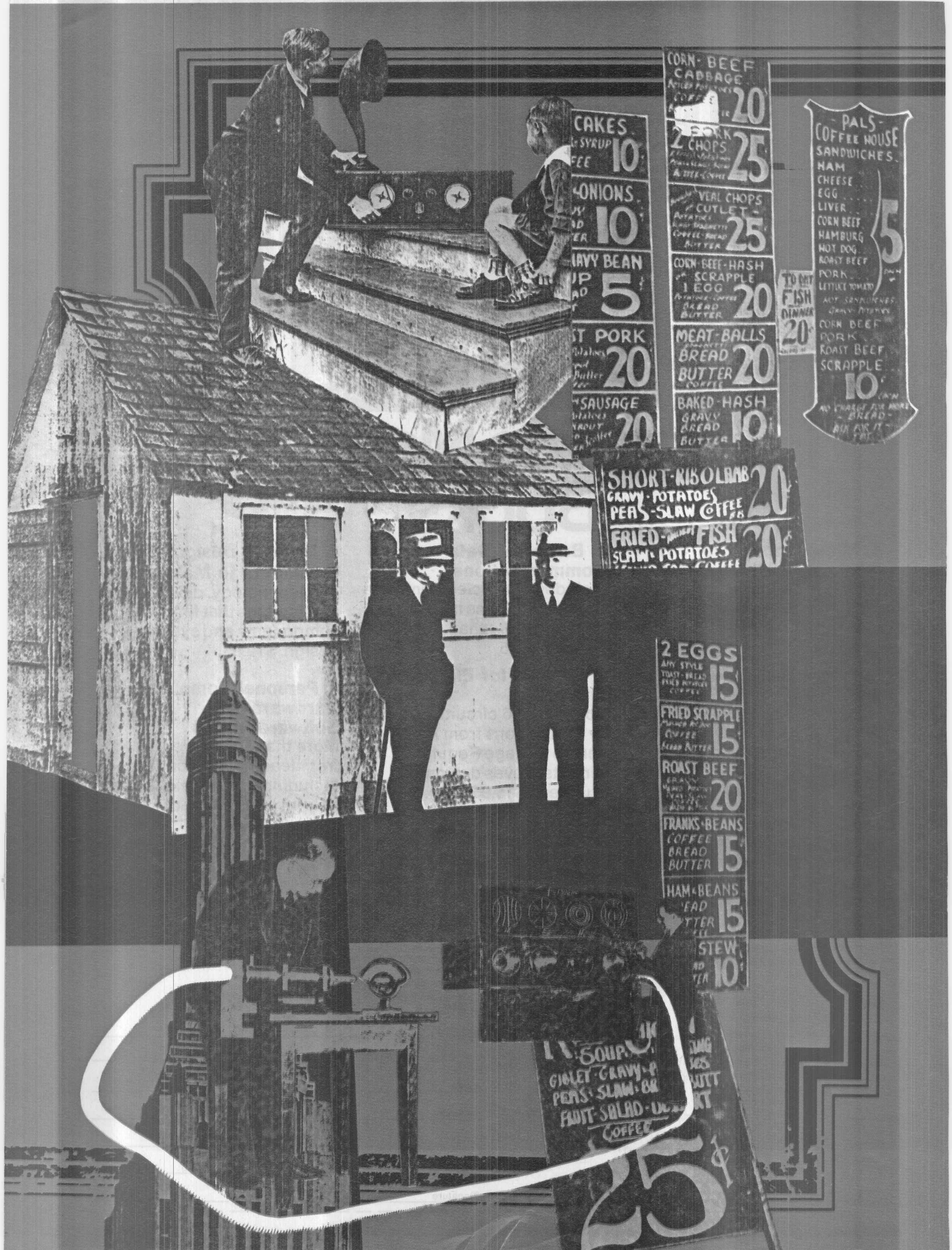
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THE RADIO YEARS

AMIDST BRIGHT PLANS FOR ITS FUTURE, ELECTRONICS MAGAZINE WAS LAUNCHED IN APRIL 1930. THE DEPRESSION WAS BEING LAUNCHED RIGHT ALONG WITH IT, THOUGH THE FEELING AT McGRAW-HILL INC. WAS THAT THINGS WERE BOUND TO GET BETTER SOON. ELECTRONICS AS AN INDUSTRY WAS ALREADY MAKING ITS MARK, HOWEVER. THE NATION WAS HELD IN THRALL BY RADIO BROADCASTING THROUGHOUT THE DECADE. INDEED, RADIO WAS THE ELECTRONICS INDUSTRY. TELEVISION BROADCASTING AND RADAR WERE LOOKED AT EXPERIMENTALLY. THEORETICAL FOUNDATIONS FOR ELECTRONIC DIGITAL COMPUTERS WERE LAID. THE OSCILLOSCOPE EMERGED AS A USEFUL TOOL, AND THE IDEA OF USING A SEMICONDUCTOR FOR AMPLIFICATION WAS PATENTED.

Chapter 3

Guglielmo Marconi didn't see the need for it, and Lee de Forest inveighed against it, but it succeeded in spite of their pessimism. The 1930s were unmistakably the golden years of commercial radio.

Marconi would have preferred standing on the Morse Code as the cornerstone of his wireless telegraphy; he saw no mission for voice transmission. De Forest warned the Institute of Radio Engineers in January 1930 that "the greed of direct advertising will rapidly work to sap the lifeblood and destroy the greatest usefulness" of radio; he damned "this reptile of etheric advertising." The radio networks were too busy learning and succeeding to give the advice much heed.

And while radio development raced ahead, there were more cautious advances in other areas of electronics:

- Television was in gestation and finally emerged from the womb in 1939 when telecasts began from the Empire State Building in New York.
- Radar was nurtured to the point where it was ready to serve when World War II broke out.
- Oscilloscopes became useful tools of measurement.
- Vacuum-tube voltmeters were developed as sensitive instruments.
- Electromechanical analog calculators and computers were perfected, and the foundation of the modern digital computer was laid.
- Researchers turned up such inviting concepts as thin films, field-effect transistors, and liquid crystals, but they were filed away to be dusted off and developed in later years.

Many developments, most of them fortunate and at least one—the Depression—unfortunate, contributed to the flowering of commercial radio. For one thing, the technical foundation was secure. By 1930 wireless telegraphy was more than 50 years old. Carrier systems were widely used to multiplex voice signals for long-distance transmission. Single-sideband transmission had been understood as early as 1915 and had been patented in 1923 by John R. Carson of American Telephone & Telegraph. And Harold S. Black of Bell Telephone Laboratories, in 1927, had already conceived of negative feedback as a cure for the nonlinearities, gain variations, and other ills of amplifiers used as repeaters in carrier systems.

Engineers made radio an electronic success. But what helped turn it into a commercial hit, perhaps more than anything else, was the Depression. In a world made

Special effects. The crack of pistol shots and the squealing tires of automobiles in chase fueled the imaginations of listeners to the Gangbusters radio program. The scene in the studio was vastly different from the exciting pictures the mind conjured up.

were ready to forget their troubles. They craved entertainment, preferably at little cost, and entertain them inexpensively commercial radio did in the 1930s, with Morton Downey, Bing Crosby, Kate Smith, Amos and Andy, Jack Benny, Fred Allen, Eddie Cantor, the Maxwell House Showboat, Gangbusters, and more, more, more. Family evenings were spent at home by the radio, and by the mid-1930s automobile motoring and radio listening were being enjoyed simultaneously by millions.

The manufacture of receivers for radio broadcasting was highly competitive. This led to millions of mass-produced sets: handsome wooden consoles at first for the parlor, as the living room was called in Middle America, and then midget radios in plastic for the kitchen, bedroom or mantelpiece. They bore names like Atwater-Kent, Philco, Majestic, and Silvertone. The midgets were growing in popularity by the turn of the decade. So many sets of all kinds were produced that *Electronics* was not three months old when the editors were scolding manufacturers:

"Every year since 1924 radio has undergone an annual overproduction. Each year manufacturers, racing for supremacy and low production costs, have swelled their bargain prices. Will the economic blunders of 1929, 1928, 1927, etc., be committed over again in 1930?"

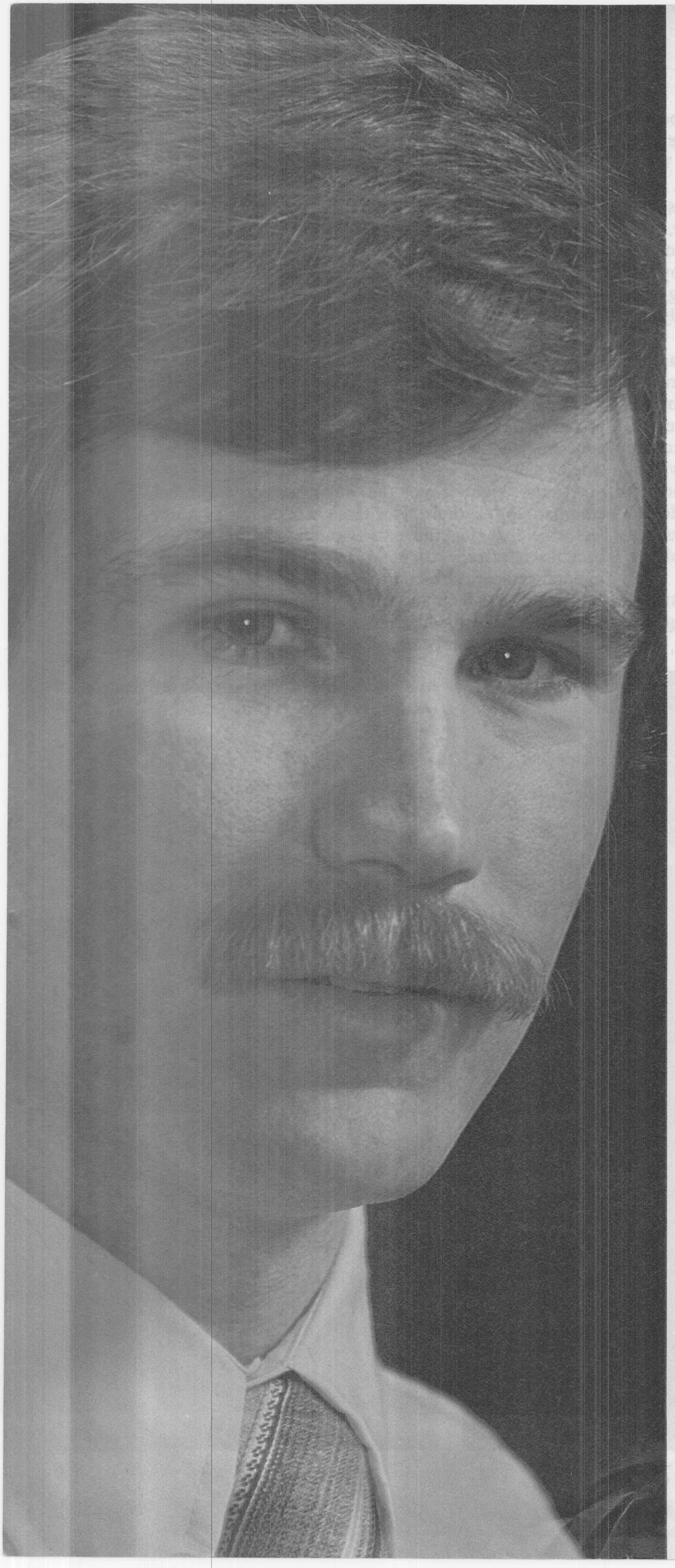
Apparently they were. In March 1931 the magazine reported that, as far as it had been able to determine, not a single radio manufacturer had made any profit from radio sales in 1930.

If one development paced the growth of radio more than any other, it was that of the vacuum tube. The triode had been invented by de Forest as far back as 1906, and by 1930 it was generally recognized that improvements in every aspect of transmission and reception of radio signals could be attained most easily by improving the vacuum tube. Thereafter it was a matter of harvesting the best of a fertile field of engineering concepts, so that tubes and other equipment advanced side by side.

At the right time the superheterodyne receiver emerged, for example. This circuit led to larger coils and less shielding for the entire tuning system. When it became necessary to compensate for oscillator drift, bimetal temperature-compensating capacitors moved to center stage. When static became increasingly troublesome, frequency modulation bowed in. One after another the technical challenges were met. The period of

Real-life couple. Marian and Jim Jordan were radio's "Fibber McGee and Molly."

Mysterious. The Shadow fought against the evil that lurked in the hearts of men.



Speaking of reliability...

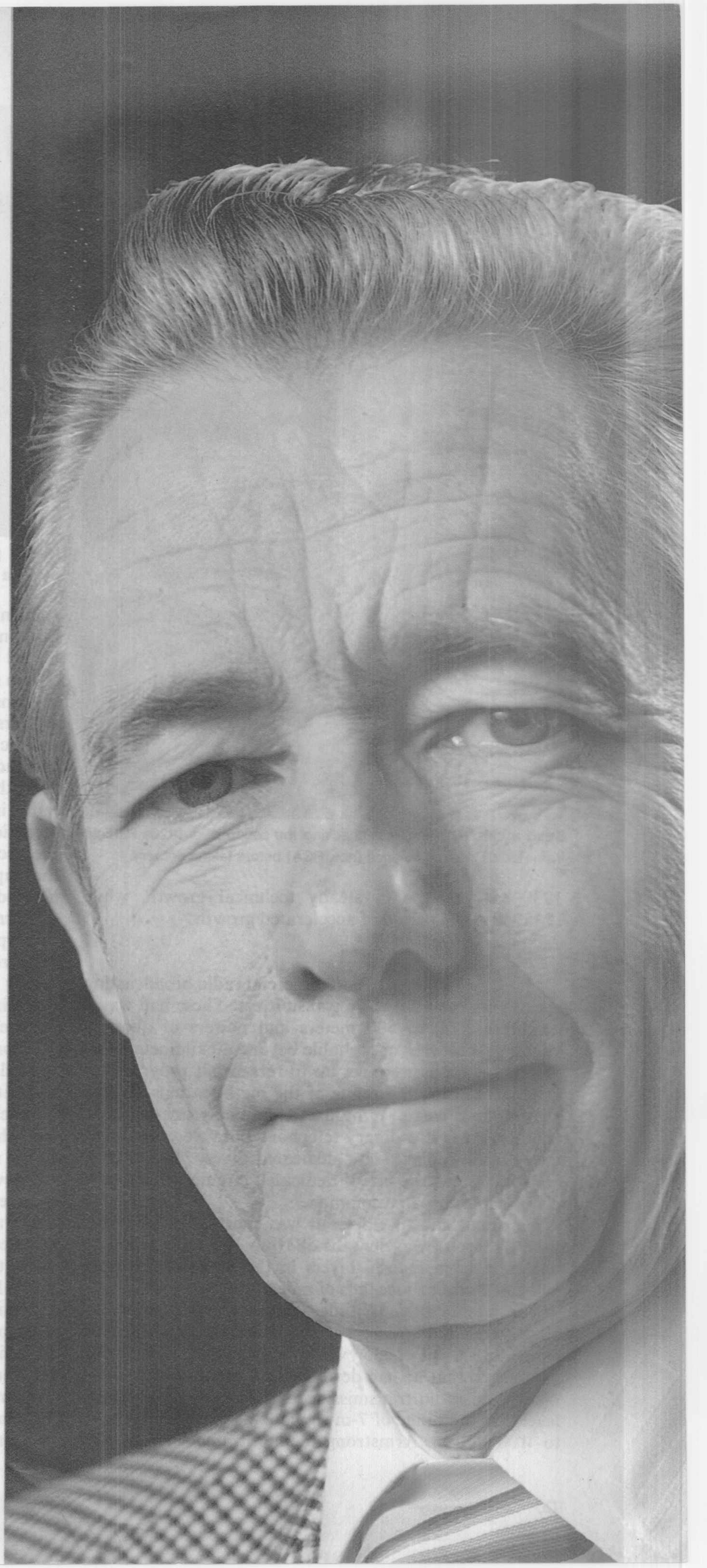
"It's a better investment."

Working with military telecommunications equipment, I've become well aware of the importance of reliability. And, looking ahead, you can see that the 'science' of reliability is certain to get increasing attention at all levels from military to commercial.

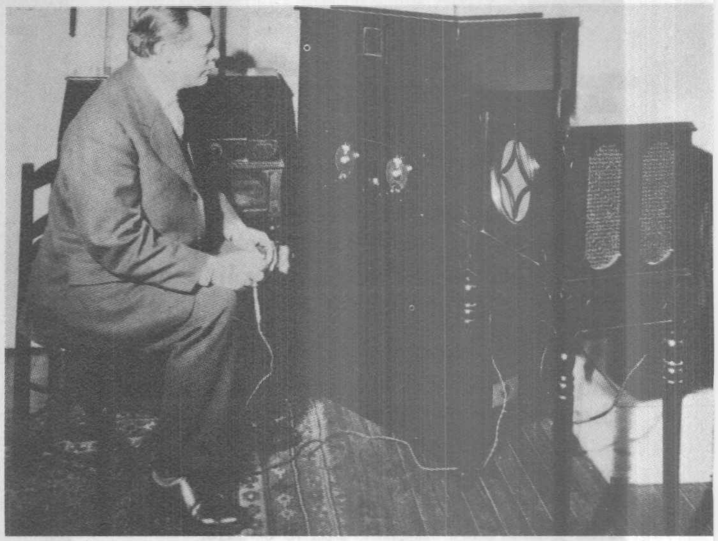
At any of these levels, the degree of reliability attained will continue to be affected by the balance of cost vs. MTBF. In working with components, I know that their MTBF is often affected by equipment design factors not related to initial quality. Parts density, cooling methods and production techniques are only a few of these. Also, through screening and thermal and electrical derating, the engineer can improve component reliability after delivery.

But in the battle of cost vs. MTBF, a vendor's concern for designing and manufacturing to high quality standards will continue to be of primary importance. In addition, interaction between vendor and OEM in setting and maintaining quality standards is going to be even more vital. Time invested in preventing failures is always a much better investment than time spent in repairing them.

Mike O'Brien
Component Application Engineer
Collins Telecommunications Products Div.
Rockwell International
Cedar Rapids, Iowa



Such music! This family is checking the sound of a 1920s Radiola from Radio Corp. of America (now RCA) before taking delivery.



Hardly portable. Electronics inventor E. F. W. Alexanderson sits before a 1926-model Radiola, an impressive piece of furniture.

1930–35 was one of steady technical growth, while 1935–40 was a period of accelerated growth.

Commercial radio broadcasting began with medium-wave transmitters. These had wavelengths of 300 to 500 meters and powers of about 3 kilowatts, but were not reliable beyond 40 kilometers.

Relay stations were set up to retransmit programs to localities outside the range of the main stations. Transmission lines carried programs from one relay center to another. At first ordinary telephone lines were used, but these were replaced by dedicated lines. As national networks grew, the use of dedicated circuits within telephone cables became common.

An important development was short-wave transmission, the use of wavelengths of 10 to 100 m. It relied on reflection from ionized layers in the upper atmosphere and could cover thousands of miles.

The fidelity of amplitude-modulated radio improved all through the 1930s, but the dramatic breakthrough came in April 1935 when Edwin H. Armstrong announced that he had developed a system of frequency-modulated radio transmission that so reduced the noise level that the range of 7-m signals was extended from 25 to 100 miles. Armstrong demonstrated side-by-side transmission of a-m and fm from the Empire State Building to his laboratory in Haddonfield, N. J. Noise buried the a-m signal, but was barely perceptible around the fm signal.

Armstrong's system contradicted the accepted theories of Carson, the AT&T physicist who, on the basis of an insufficiently general mathematical analysis of fm, had concluded in 1924 that "noise, like the poor, will always be with us." Fm was Armstrong's crowning glory as a radio innovator, his earlier endeavors having been the invention or development (it is often unclear which) of the oscillator (1912), the regenerative receiver (1912), the superregenerative receiver (1922), and the superheterodyne receiver (1920).

Electronics' editors embraced fm wholeheartedly, and this apparently caused some difficulty. In a January 1940 review of fm, they remarked that they had been "flatly accused of taking the side of the inventor in reporting demonstrations enthusiastically." They acknowledged that this was the case, and defended their position on the grounds that "the system, as demonstrated, really does perform with startling high fidelity and with startling freedom from noise."

Fidelity and noise-free reception, however, were not enough to make fm an immediate commercial success. Radio manufacturers questioned whether enthusiasm for the new medium would ruin what little prosperity they were enjoying in the late 1930s. Broadcasters argued that transmitters were at least 2,000 hertz wider than the best receivers tuned into a station and perhaps 6,000 Hz wider than the worst, and "the public apparently doesn't give a hoot."

Armstrong spent more than $1 million to develop microphones, audio amplifiers, and other components, and his fm station went on the air in the very high-frequency spectrum in 1939. By November of that year five fm stations were operating under FCC license, and 15 stations were operating under FCC construction permits. In 1941 the first fm chain, designated

a components manufacturer that continues to excel internationally.

Founded with a handful of employees in a New England seacoast town, Sprague Electric began manufacturing capacitors in 1926, four years before *Electronics* magazine was born. Since then, Sprague has grown to a worldwide organization with plants in the Far East, Europe, Canada, Mexico, and more than a dozen states here at home.

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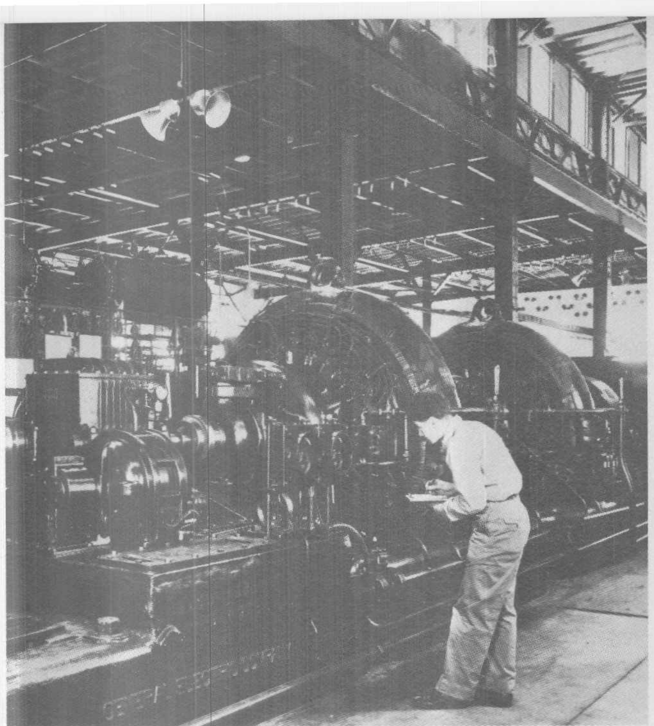


Sources. Alexanderson alternators at RCA's Rocky Point, N. Y., transmitter once carried the whole load of overseas radio traffic.

the Yankee Network, was operating in New England.

A lesser-known development but one that proved significant many years later was pulse-code modulation, which was introduced by R. H. Reeves of France in 1938. By understanding the relation between information content and bandwidth, Reeves may have come up with the first true communications system based on statistics theory. In the previous year, as it happened, Claude E. Shannon, whose later work was to give PCM a theoretical basis and correct that of fm, made his initial contribution to information theory. He showed that the behavior of complex switching circuits could be analyzed by means of Boolean logic.

Although some executives feared that the manufacture of radio sets was approaching saturation in the late 1930s (in some cities more than 60% of the homes owned a radio), and although there was a continuous shakeout of manufacturers, engineering advances showed up in the new lines. The superheterodyne circuit had been introduced in 1920, and that year also saw the installation of a tone control, with which the listener could obtain more effective bass by reducing the treble response. In 1932 manufacturers introduced automatic muting circuits to cut the noise between carrier waves. That was also the year they began putting volume and tone controls on the same shaft; as the listener turned down the volume, the bass and treble increased.

Engineers wanted to improve radio fidelity, but *Electronics* noted that "sales departments decided that high-quality sound was all right for engineers, but not for the public." The growing demand for midget radios not only drove down the price of all sets—from an average of $115 in 1928 to $81.50 in 1930—but fidelity also slid. In January 1931, the editors of *Electronics* remarked somewhat plaintively, "There must be some way to better the fidelity of the small sets." Later that year they commented, "Quality of receivers hit an all-time low: poor workmanship, poor tone fidelity, low prices."

Some manufacturers argued that the public wanted lower prices, not higher fidelity. *Electronics* said: "To state that listeners do not want to hear frequencies above 3,000 cycles controverts the experience of composers and musicians of several hundred years."

Still there was some interest in higher-quality sound, because in September 1935 the magazine reported new radio circuits that extended the audio range toward the low and high frequencies, reduced harmonic distortion, increased available power output, and improved speaker characteristics. It was the year the manufacturers began using cathode-ray tuning indicators in radios—so-called magic eyes.

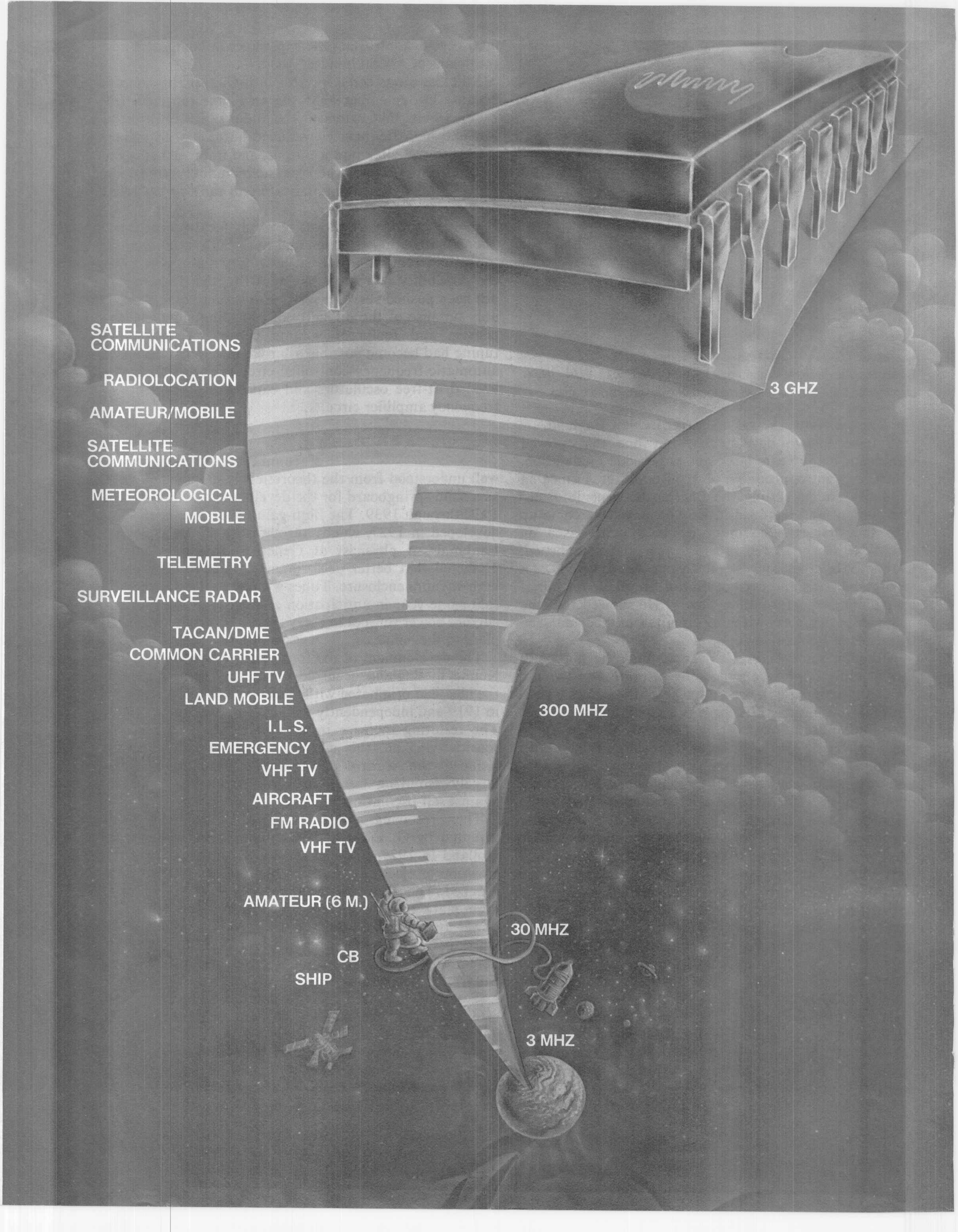
In 1937 the big news was in mechanical tuning: telephone-dial station selection and push-button "automatic tuning" in addition to the earlier rotary dials. There was the possibility of remote tuning. "But this feature has not been pushed very actively," *Electronics* noted, "probably because of the difficulty of providing simple, inexpensive and foolproof volume control." Mechanical tuning had become possible after engineers had designed automatic frequency-controlled circuits as well as stabilized drift-free oscillators and expanding intermediate-frequency amplifier circuits.

Vacuum tubes were sufficiently well understood from the theoretical standpoint to serve as a solid springboard for the development of radio from 1930 through 1939. The high-gain triode had been fully developed in 1927, chiefly through the efforts of Irving Langmuir, a physicist at General Electric, who had predicted that better performance would result from a high-vacuum enclosure. Tubes with ac heaters were built that same year in anticipation of the use of alternating-current power sources to carry electricity from the power plant to the home.

The development of the four-element tetrode by H. J. Round in England occurred about that time, although the idea had originated with Germany's Walter Schottky in 1919 and independently with GE's A. W. Hull in 1923. The resulting increase in tube gain improved receiver sensitivity. And the additional grid in the tetrode reduced the control-grid-to-anode capacitance, too, largely removing the need for neutralizing the tube against self-oscillation.

Then receiving and small-power rf pentodes were invented by G. Holst and Benjamin D. H. Tellegen in Holland in 1929, and the effects of random secondary emission of electrons from the plate of the tetrode were reduced. The result was a tube that had very high gain, high plate resistance, and uniform characteristics. In power tubes, the pentode could provide power at high plate dissipation without excessive distortion. The variable-mu tetrode and pentode, developed in 1930 by Stuart Ballantine and H. A. Snow at Radio Frequency Laboratories, reduced cross modulation in receivers and also decreased the number of parts needed to build automatic gain-control circuits.

As vehicular communications became popular and it became obvious that the vhf regions of the spectrum would soon be totally occupied, the country's major tube researchers—the Radio Corp. of America (RCA today),



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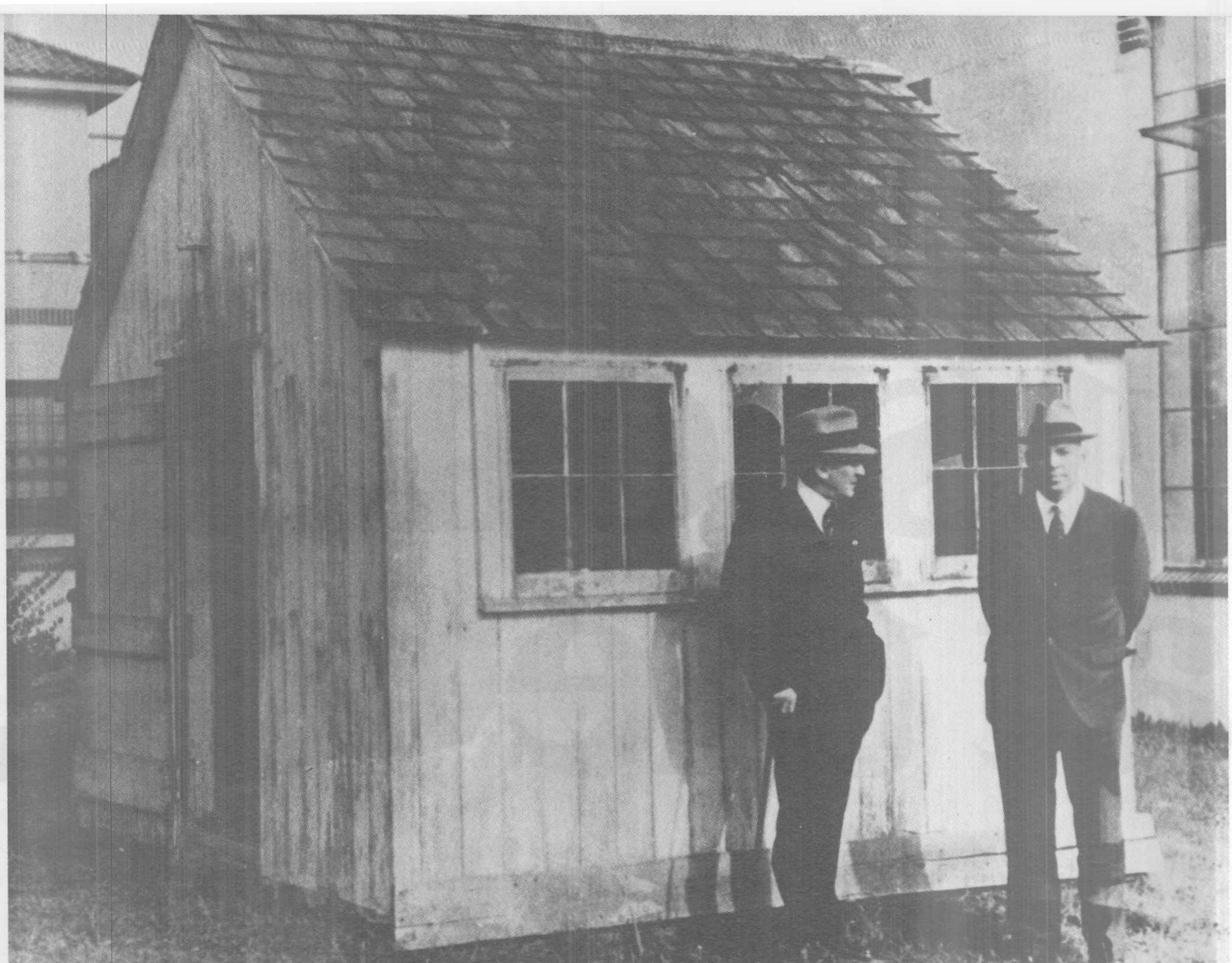

Beginnings. Edwin Howard Armstrong, right, met with Guglielmo Marconi on Marconi's last visit to the U. S. in 1932. Here they pose in front of the shack in which Marconi, the inventor of wireless telegraphy, built the first wireless transmitting station in the U. S. in 1900.

GE, Westinghouse, and Raytheon—pursued work on three fronts. The areas of interest were consolidation of tube function, the development of more tubes, and an attempt to increase the tubes' upper frequency limit. The multifunction heptode (1932), the hexode (1933), and the pentagrid converter (1933) resulted, along with metal-envelope tubes (1935). The tiny acorn tube (1933) permitted reliable operation into the vhf region.

A sign of the times was that in 1932 *Electronics* listed 300 different tube types (double the previous year). Around this time Sylvania came out with a line of 6.3-volt filament tubes. This tube line came to be adopted by all radio set manufacturers.

Passing almost unnoticed was the conception of the junction field-effect transistor, or J-FET, by Germany's Oskar Heil in 1935. The metal-oxide-semiconductor FET, or MOS FET, had also been envisioned in 1925 by Julius Lilienfeld (see Chapter 5). But as the technology had not reached the point where a device would be feasible, not much commercial interest was forthcoming.

Optoelectronics, on the other hand, proved highly marketable. Electric eyes proliferated in the 1930s. To the public's amazement, these phototube amplifier circuits made restaurant doors swing open ahead of waiters, and they also found many industrial uses.

Beam tetrode tubes for both transmitting and receiving were introduced in 1936, providing superior performance to a pentode without the need for a suppressor grid. The beam construction let large plate currents be drawn at relatively low plate voltage, thereby increasing the tube's power sensitivity. The popular zero-bias class B tube made its debut in 1936 also.

With the introduction of the indirectly heated cathode (heater filament) in the power pentode, transconductances were boosted by a factor of 4; in the best tubes then available, transconductances of 6,000 siemens were achieved. Wideband amplifiers became popular, too, with the introduction of remote-cutoff tubes that could yield transconductances as high as 9,000 siemens. Finally the door-knob tube for ultrahigh frequencies was introduced in 1938 and the coplanar triode at about the same time, completing the most productive era in the history of vacuum-tube development.

Automobile radio barely existed at the beginning of the decade. The January 1932 issue of *Electronics* reported that only about 100,000 car radios were sold in the U. S. in 1931, compared with a total of some 3 million sets. Among the deterrents, it said, was "the opinion often and publicly expressed that automobiles are no places for radio sets, that the driver should suffer no further attention diversion." But there were technical problems as well. They included a battery drain that reduced normal battery life from two years to one and spark-plug noise in the receiver ("One manufac-

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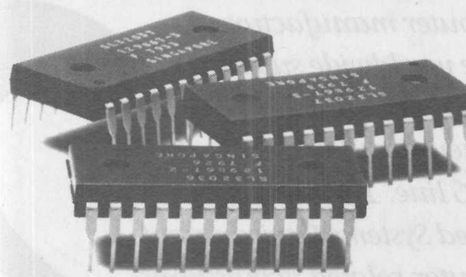

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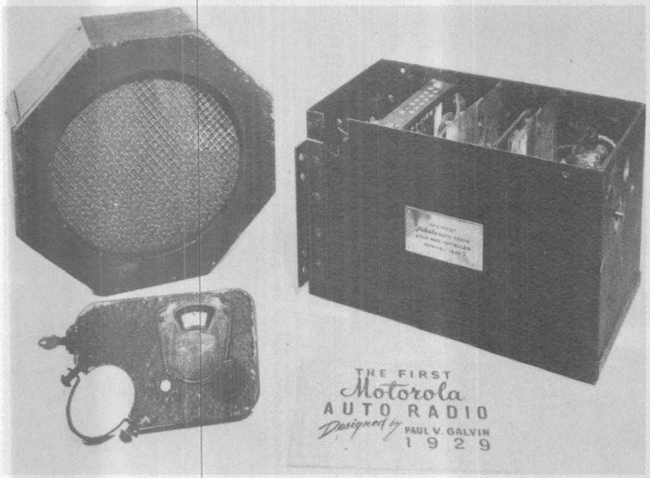


First car radio. Motorola (then Galvin Manufacturing) introduced it at the 1930 convention of the Radio Manufacturers' Association.

Calling Car 178. The police in the early 1930s bought receivers and transmitters from Motorola for communication with their patrol cars.

turer," *Electronics* said, "found that radio-frequency racket persisted until he had soldered the oil pressure and water lines to the frame of the car"). The sets were relatively fragile. Finally there was the price; automobile manufacturers and dealers felt that a radio should not cost more than 10% of the car's price, which in 1932 was usually around $600.

It was obvious, however, that entertainment-minded consumers wanted automobile radios, and *Electronics* forecast that during 1932 the industry would sell 250,000 sets at an average retail price of $45. In fact, almost 725,000 sets were sold at $55, and in February 1934 the editors noted that the automobile radios "seen recently are much more sturdy in construction than those of a year ago."

"These sets," the magazine said, "are not only stronger physically, but easier to install, more immune from vibration troubles and in addition easier to service when something goes wrong."

By then mobile radio communication was recognized as a potentially lucrative market. A student at Purdue University, Robert Batts, had helped the Detroit Police straighten out their difficulties with one-way voice transmission to patrol cars. Batts, who once had worked in a radio parts store and had become friendly with a policeman from the Detroit force, designed the force's first acceptable receiver for a patrol car and installed it in April 1928. With six tubes (three tuned rf stages), it employed screen-grid tubes to avoid oscillation, copper-shielded compartments to reduce stray coupling, and lock-tuned capacitors to improve electrical and mechanical stability. The system was deemed a success in helping to fight crime.

Sets for the first two-way police network (transmitters and receivers at both ends) were installed in patrol cars in Bayonne, N. J., in 1933. Operating at about 33 megahertz, the sets were equipped with superregenerative receivers and tuned-circuit oscillators.

The police in Indianapolis were the first to use superheterodyne receivers. Their system, designed by Batts, was as successful as his first system in Detroit.

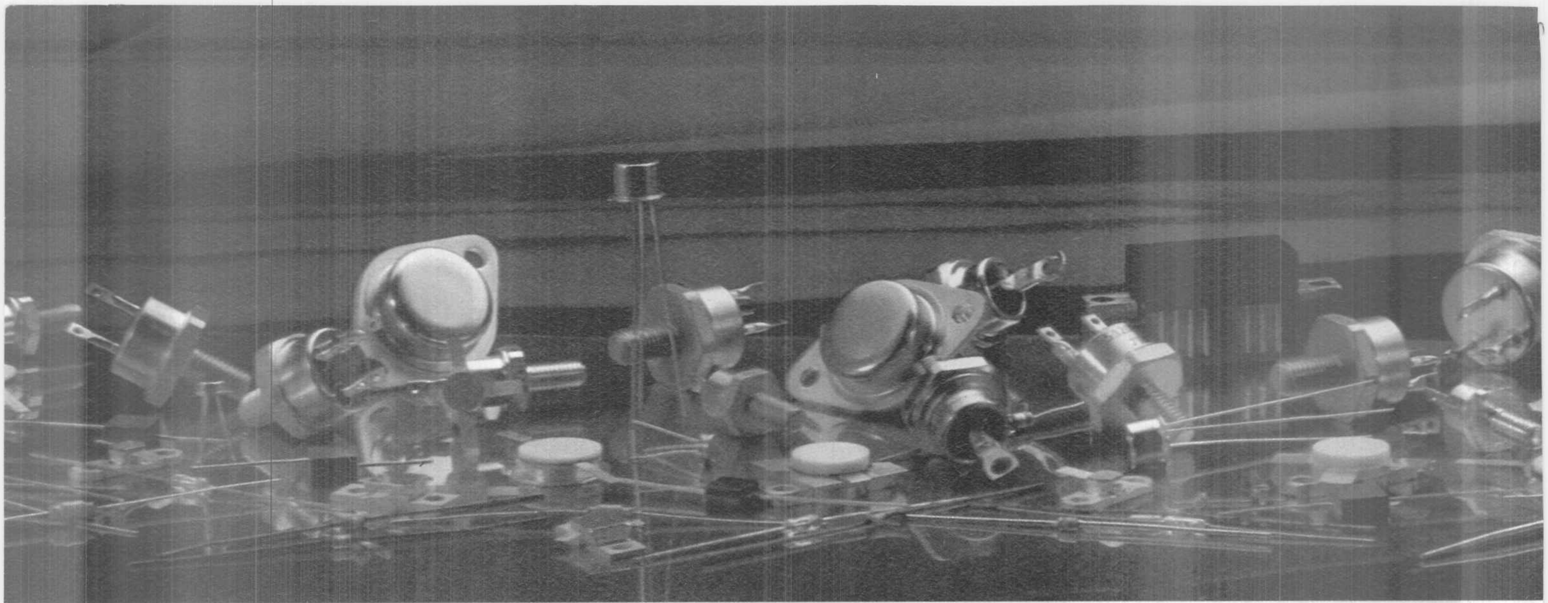
Meanwhile commercial advances in mobile radio brought forth the dynamotor power supply (Bosch Corp., 1931) and the vibrator power supply (Mallory, 1931). RCA and GE entered the mobile radio field in 1936, and Motorola followed a year later. As a result of the success of police radio, the Federal Communications Commission in 1936 allocated 29 permanent channels for police communications in the band between 30 and 40 MHz. Interest in mobile communications then quickly spread to other areas, including industry and eventually personal radio.

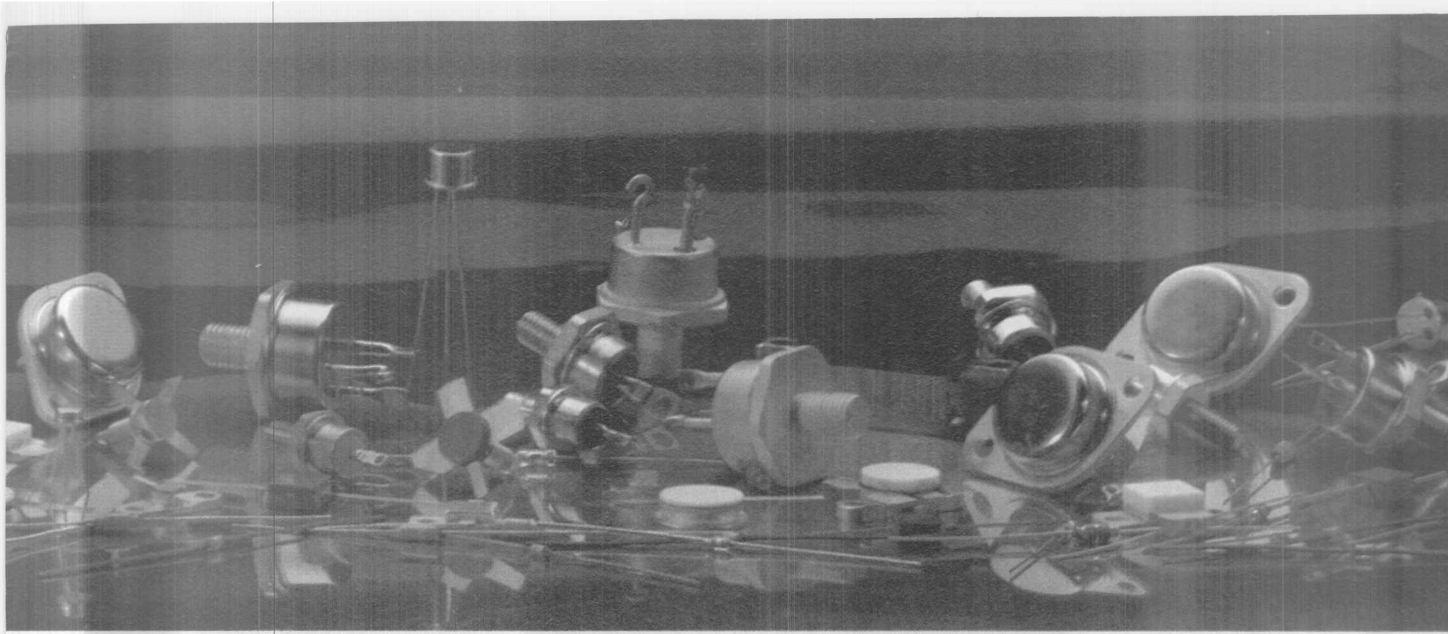
By now the frequency interference problems that had plagued early commercial broadcasting were becoming a memory. The present, controlled era in radio broadcasting dates from 1934, when Congress passed the New Deal legislation setting up the Federal Communications Commission. The number of commissioners was increased to seven, and control over the airwaves was tightened. The Communications Act of 1934 consolidated authority over both wire and wireless communications—point-to-point and broadcasting—in a single agency, the FCC. Empowered to revoke broadcasting licenses, the FCC moved the industry into what became known as the "cleaning up" period (1934–38).

By 1940, there were 777 a-m stations in the country, fm stations were taking root, and close to 500 million radio receivers were in use. International broadcasting was rapidly expanding in the high-frequency (3-to-30-MHz) portion of the spectrum. And commercial television was on the nation's threshold.

Television: it promised to be the largest show-biz attraction to hit the American home. David L. Sarnoff, then vice president and general manager of RCA, saw the medium in 1923 as an "adjunct" to radio that "will make it possible for those at home to see as well as hear what is going on at the broadcast station." It "will come to pass in due course," he confidently told his board of directors. The 1930s gave birth to television.

Development of the camera tube was of primary interest. It started in the 1920s (see chapter 2) and before the





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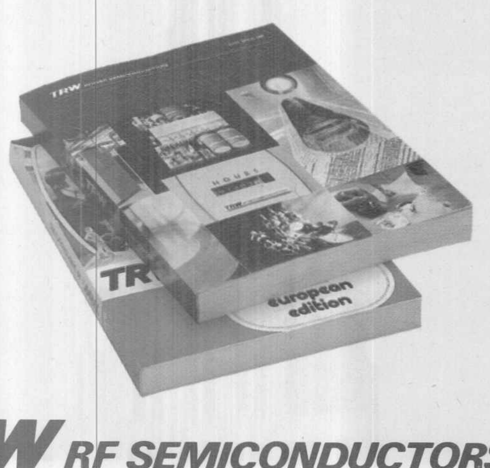

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Demo. Bell Telephone Laboratories' Herbert Ives holds giant photoelectric cell that picked up signals at Bell's first public demonstration of TV on April 7, 1927. Screen (right) uses a meandering neon tube with electrodes placed so as to form a 2,500-element picture grid.

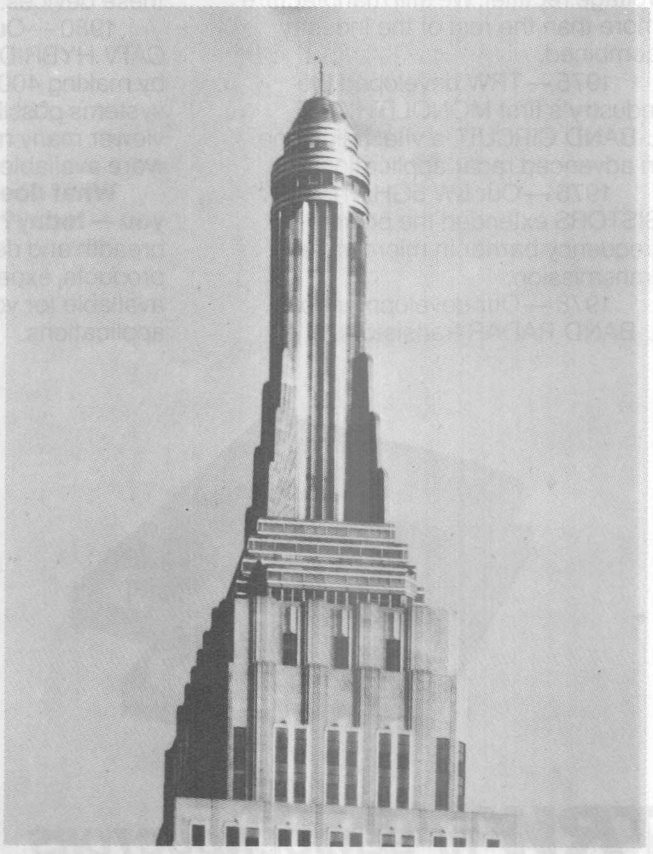
1930s were over two completely different systems were in competition with each other: an electromechanical approach and an all-electronic one.

The belief that an all-electronic system would be superior to the electromechanical appeared at the start of the 1930s, but it would be 7 years in Britain and more than 10 in the U. S. before the final verdict from the regulatory commissions emerged. In the interval many enterprising individuals and some pure researchers dedicated a goodly portion of their lives to finding a feasible solution. Among them were Herbert Ives of Bell Telephone Laboratories (color TV); Ernst F. W. Alexanderson of General Electric (a mirror-based scanning system for a mechanical TV approach); Germany's Manfred von Ardenne (a flying-spot cathode-ray tube for receiving images); and Allen B. Du Mont, who made significant contributions to the development of the CRT.

In August 1930, *Electronics* discussed what was needed to give television entertainment and commercial value: "We could hardly expect the home reproducer to be used for several hours a week unless one could not only recognize the face but also observe every shade of facial expression. The observer would expect to discriminate the wrinkles about the eyes and mouth when the speaker smiles, see the eyebrows change their position and observe the eyelids open and close, because it is such details which make up expression."

The writer argued that no mechanical systems could provide enough picture elements to meet these requirements, that only electrons offered sufficient control.

In June 1931 *Electronics* reported that television was a



No King Kong. Experimental TV antenna installed by RCA in the Empire State Building broadcast its first signal on Oct. 30, 1931.

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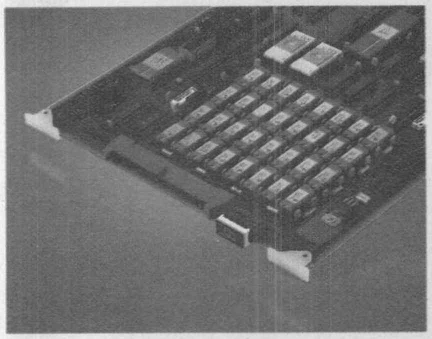

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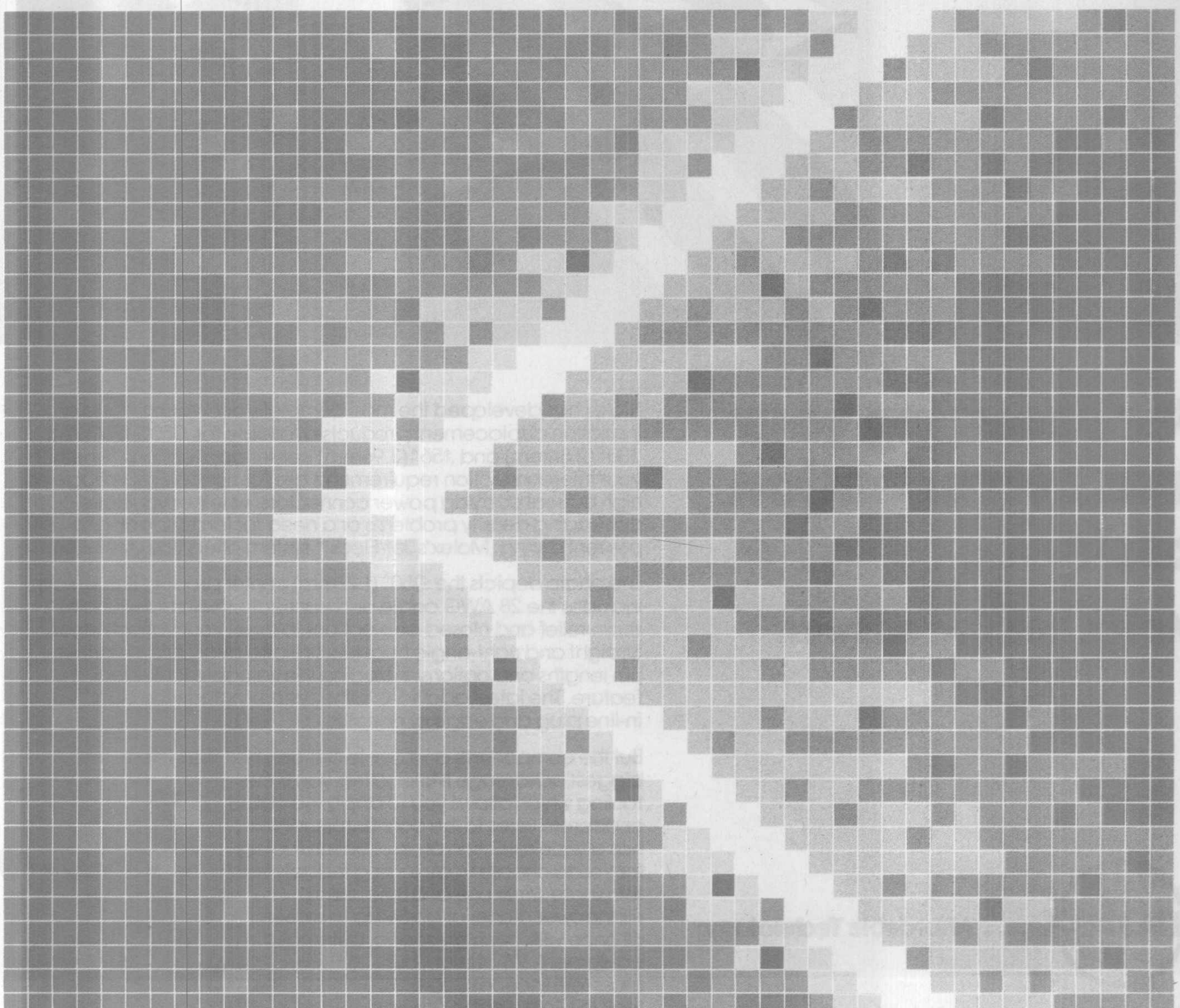

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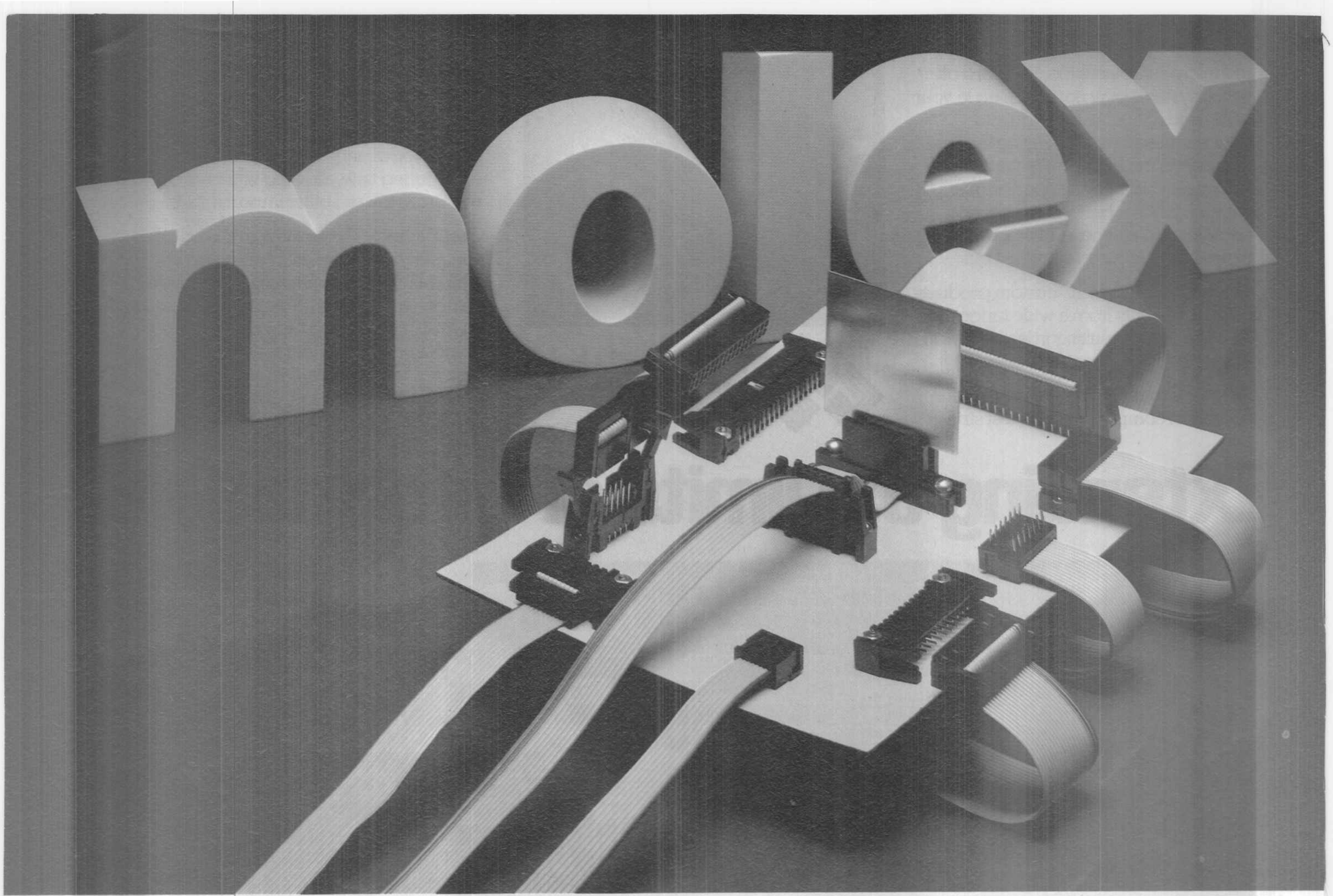
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crude device for enthusiasts only, noting that in Boston one station was telecasting to owners of sets "bought in the form of parts from Kresge stores."

"In New York no less than four stations are on the air," the magazine observed. "Radio dealers, using television sets as curiosity-creators, have so far furnished the largest outlet for television receivers. Whether they can interest other 'lookers' sufficiently to spend from $100 to $300 for a televisor depends."

The National Broadcasting Co. completed the first television antenna on top of the Empire State Building in 1932, but at the end of the following year there were still major problems: a lack of picture detail (the number of scanning lines ranged from 45 to 343), the high cost of receivers, short transmitter range, difficulty in running stations together for network programs, and tremendous studio expense.

In May 1934, W. R. G. Baker, RCA Victor's general manager, addressed the problem of studio expense and concluded that it was at that time insoluble. He estimated that if 700,000 people bought TV sets, they would require 80 transmitters that, with a network, would cost $58 million a year to operate, maintain, and replace. The total investment in the broadcast industry was then about $25 million, and this had been spent over 10 years.

Programming was another problem: "A radio broadcast station is likely to have 5,000 program hours a year," Baker noted. "For a television station to show once each of the 300 feature motion pictures produced a year in the United States would take up only 300 or 350 program hours. To broadcast once each of the new plays shown on New York stages would take up only another 300 hours. Shorts and newsreels would bring the total only to 2,000 hours, and not all news events would be in reach."

Electronics surveyed the status of television in October 1934, comparing various systems. The six companies mentioned used different numbers of scanning lines—from 60 to more than 400. Most transmitted 24 pictures a second (the motion-picture rate). Three systems—RCA Victor, Philco, and Television Laboratories—used cathode-ray tube receivers (with green phospor); the others used mechanical devices. It was obvious that television required standards so that development could be orderly.

It was important to decide how many scanning lines should be used, whether they should be interlaced and what field and frame rates they required. These decisions influenced video bandwidth (and, in turn, transmitter and receiver bandwidth), picture flicker, and deflection-circuit frequencies. The Radio Manufacturers Association (now the Electronic Industries Association) formed a Television Standards Committee. As early as 1931, it had recommended the allocation of vhf channels, and in 1936 and 1938 it recommended TV transmission standards. But as there was no unanimity in the industry, (Philco and DuMont disagreed with the proposals), the FCC did not set standards until 1941. The number of lines was then set at 525, transmission at 60 fields per second and interlaced 2 to 1, and video bandwidth at 4.24 MHz. In Britain, where scheduled telecasts had begun in 1936 and George VI's coronation was viewed over a wide area in 1937, a 405-line standard was adopted; in France an 819-line standard emerged.

Actor. Felix the Cat, rotated on phonograph turntable, was a TV performer for experimental telecasts in 1930 over station W2XBS.

Meanwhile, throughout the 1930s in the U. S., the radio industry was reluctant to allow television to jeopardize its profitable broadcasting business, and this lack of interest was reflected in FCC inaction. The issue was further complicated by the fact that RCA, the dominant organization in TV broadcasting, was committed to its own electronic scanning approach, which was clearly many years away from commercial reality, rather than to the more immediately available mechanical scanning techniques, such as Du Mont's.

U. S. television finally showed its potential at the New York World's Fair in April 1939, when RCA began telecasting regularly from its Empire State Building transmitter. A few receivers were placed on sale at $625 each (new cars could be bought for $900), and visitors to the fair could watch the Republican National Convention of 1940 live from Philadelphia. Transmission was

CRT man. Allen B. Du Mont, shown in late 1940s photo, helped develop the cathode-ray tube for application in oscilloscopes.

THE NEXT GREAT

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The new demands of digital logic are what Bill Moore, Biomation's first chief engineer, had in mind when he developed the logic analyzer, back in '73. He called it a "glitch fixer," designed to track and unravel the mysterious electronic glitches that plague digital logic designs.

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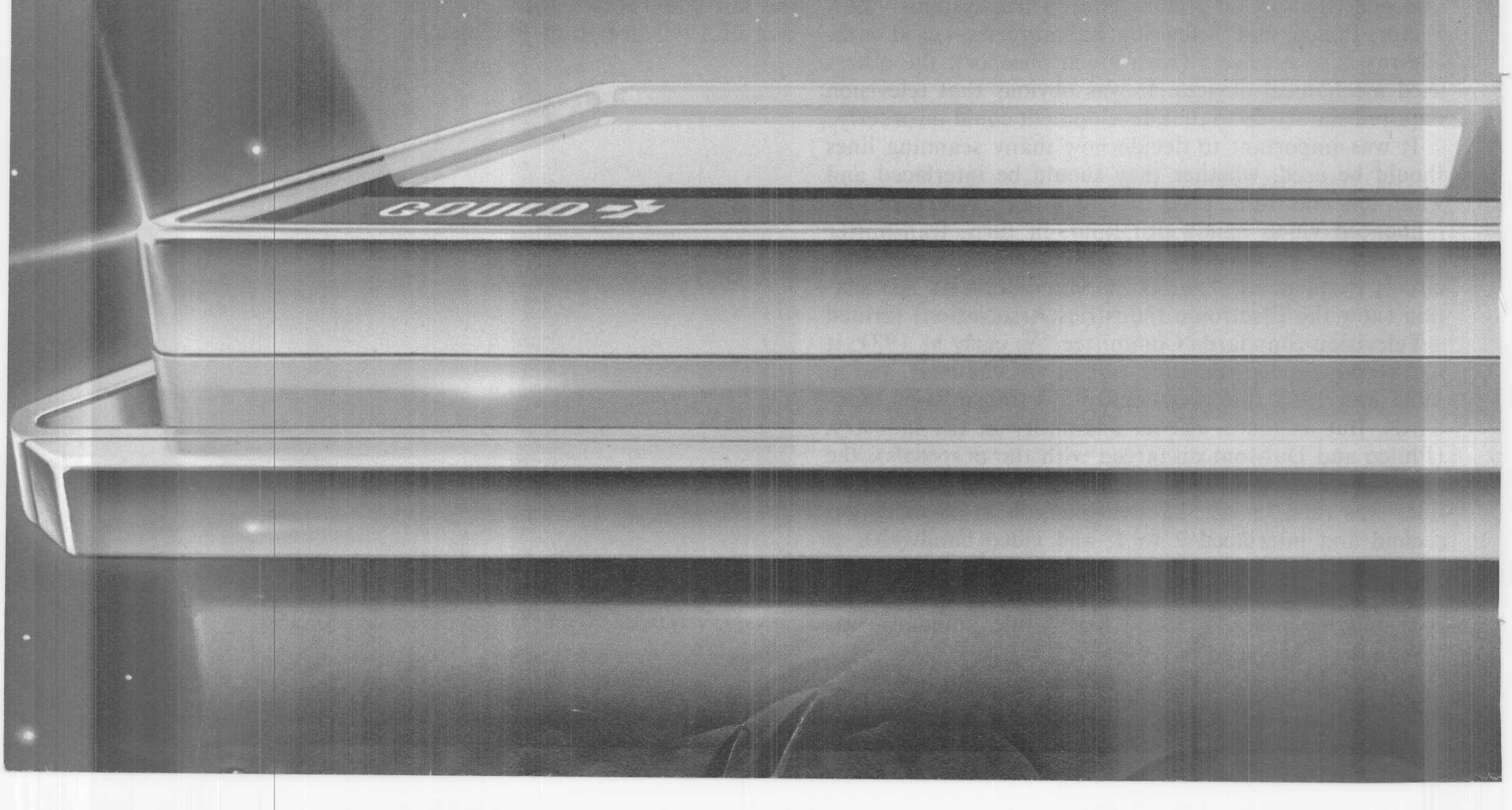
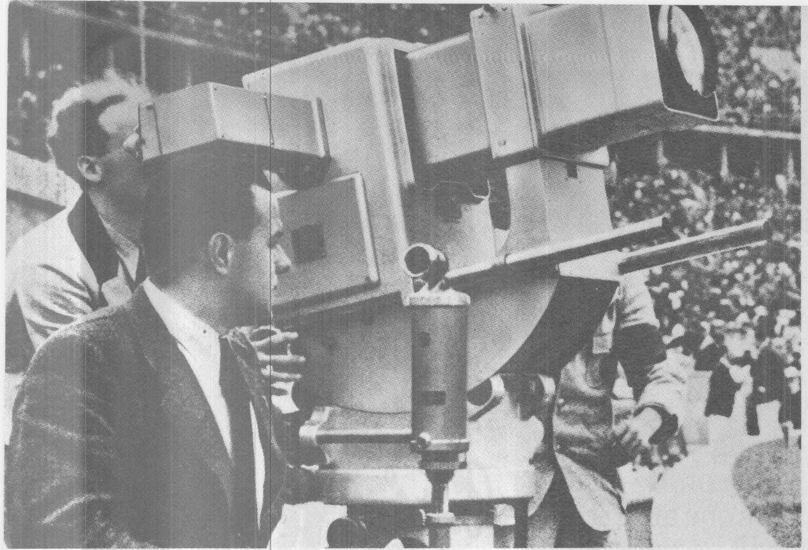




Olympian. Telefunken used iconoscope TV camera at 1936 Berlin Olympics. Cameraman Walter Bruch later invented PAL color TV.

via an AT&T experimental coaxial cable authorized by the FCC in 1936.

Subsequently six companies announced that they would produce TV sets for the New York market: the American Television Corp., Andrea Radio Corp., Allen B. DuMont Laboratories, General Electric, Philco Radio and Television Corp., and the RCA Manufacturing Co. Set prices ranged from $125 for a two-channel model with a three-inch screen to $595 for a 12-inch model that received seven channels and contained an automatic phonograph as well. These were monochrome sets, of course. Color TV emerged briefly in 1940 (see chapter 4), but World War II halted further developments.

Radio was the star and television played a supporting role in the communications drama of the 1930s, but other electronic developments waited impatiently in the wings. While some waited, they polished and improved their acts. And some new stars were born.

By the early 1930s, further improvement in radio and telephone system signal-to-noise ratios was limited by amplifier distortion. Until then, amplifiers had to provide only a small amount of amplification since telephone and radio links covered only short distances. But with the growth of longer lines of communication, high amplifications were needed.

When the amplifiers were operating to deliver this power, they had to operate in the so-called nonlinear portion of their input-output characteristics. These nonlinearities were in the relationship between the instantaneous input and output voltages of vacuum-tube amplifiers. While not too much of a problem in amplifiers that are intended to handle one signal at a time, the distortion becomes intolerable when two or more channels are fed through the same amplifier, as they are in a carrier system.

What happens is that the nonlinearity actually generates new frequency components in the output signal. These are produced by the interaction of the signals in the different channels. The result is cross modulation—elements of the speech in one channel are transferred to another. The solution of the problem is the elimination of its cause. And the way to do that is to apply negative feedback.

This concept is perhaps one of the most basic in the history of electronics. As already noted, it was discovered by Black of Bell Laboratories in 1927. What negative feedback does is to feed some of the amplifier output signal back to the input in phase opposition to the input signal. Even if the original amplification is nonlinear, the resulting new amplification is practically linear. What is more, if the original amplification factor (gain) tends to drift over time, the new (lower) gain of the feedback amplifier is practically constant.

Amplifiers based on Black's feedback concept soon became the prevalent method for maintaining high-amplification, low-distortion lines. These amplifiers had, as a side benefit, a wider bandwidth than nonfeedback amplifiers. So, from about 1934, there was little problem in extending the telephone system by use of very wide bandwidths with many channels on conductors. The standard soon became basic groups of 12 speech channels in the frequency range of 60 to 180 kHz, which allowed 4-kHz channel spacing. This is the basic system used today, except for the addition of higher levels of multipliers and supergroups. Since the line costs per speech channel are drastically reduced by this approach, cheaper long-distance calls become possible .

Whether telephone switching should be manual or automatic is essentially an economic matter. The controversy itself dates to the beginning of telephony when both manual and electromechanical switches were used. Where the number of calls per subscriber is high, it is cheaper to use an automatic exchange. And, of course, whether the calls are long- or short-distance is a major consideration. Long-distance calls have to be routed through many switching centers; short-distance calls do not. Since in the 1930s long-distance telephony grew slowly, there was no big need for automatic networks.

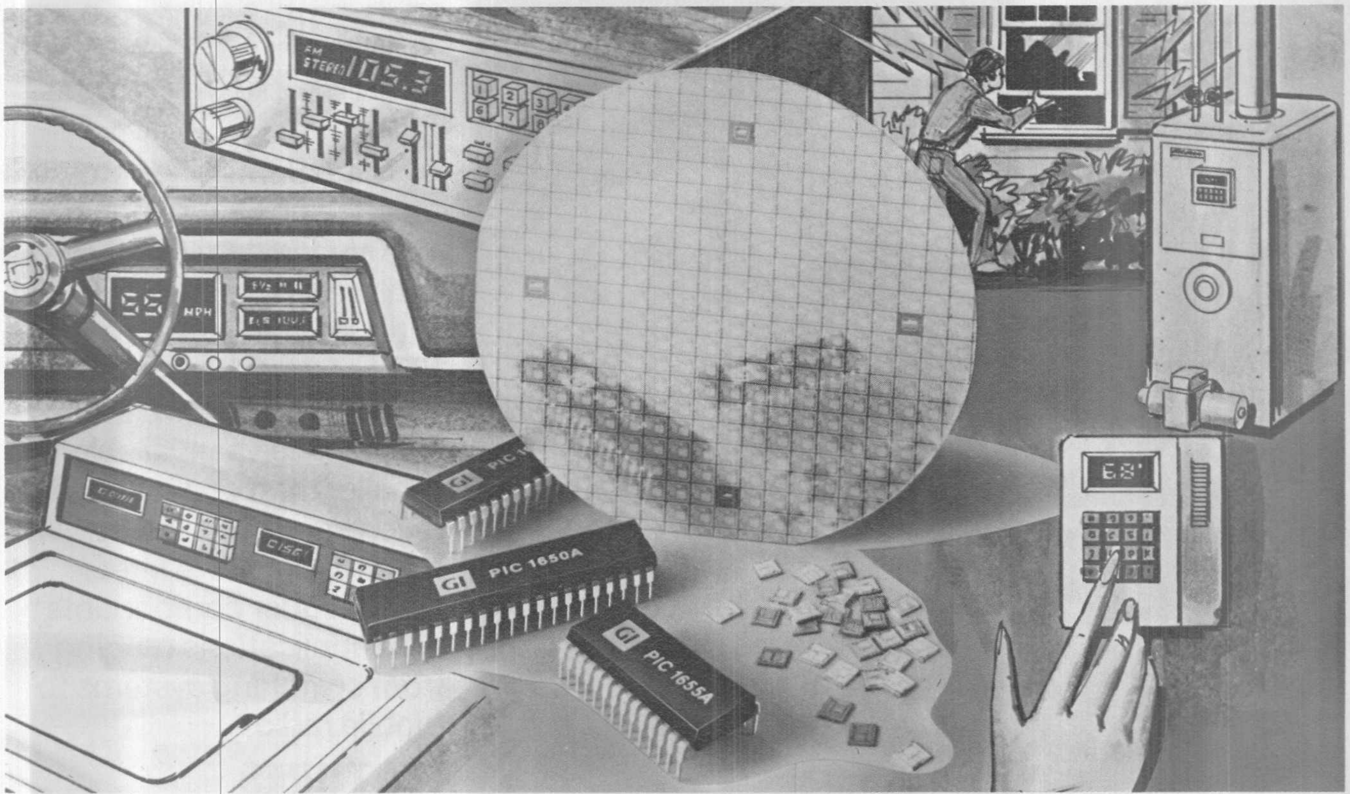
Of course, all the systems had to be compatible. Automatic exchange offices had to retain some manual exchanges as it was not economic to replace them until adequate return had been obtained on their cost.

One future star was radar (an acronym for "ratio detection and ranging"). Like other communications systems, it did not emerge suddenly, full-blown, from the hand of one inventor. Many researchers contributed to its evolutionary development. Early observers did not even know what they had stumbled upon.

In September 1922, two Navy experimenters, A. Hoyt Taylor and Leo C. Young, were engaged in high-frequency radio-communication tests across the Potomac when a passing vessel intercepted the propagation path between transmitter and receiver. The interruption was noticed by Taylor and Young. They were aware of the problem of screening naval forces from penetration by other ships in darkness and fog, and though their observation was unrelated to their radio experiment, the application was obvious. They proposed that high-frequency radio transmitters and receivers be installed on destroyers to detect the passage of other ships between any two destroyers in radio contact.

It wasn't radar. It didn't even involve reflection of

Prove Our Point.



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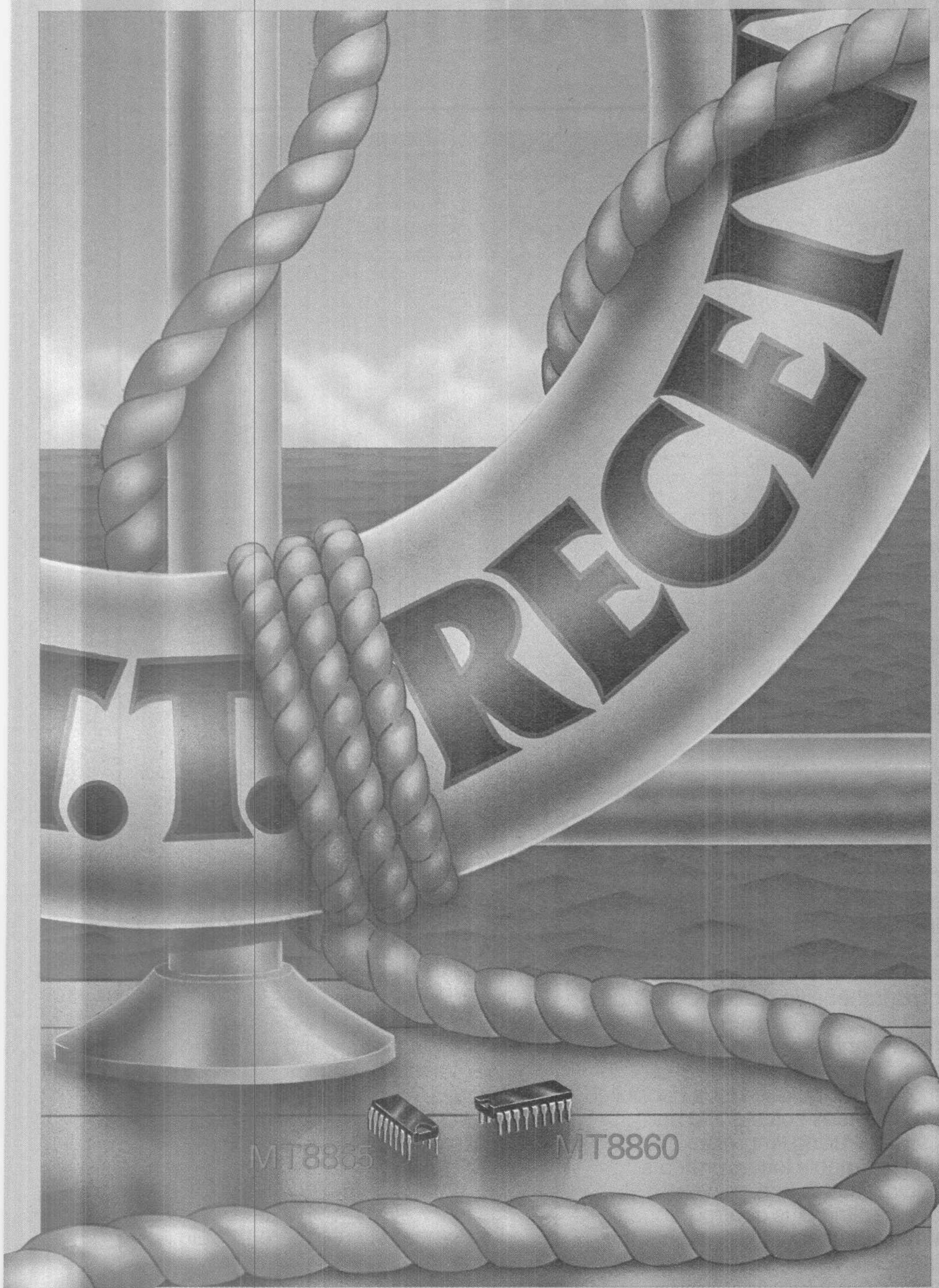

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Covering the news. Radio Corp. of America president David Sarnoff stood in front of a television camera and dedicated RCA's pavilion at the 1939 New York World's Fair. The dedication was one of the first in the U. S. at which the fledgling TV medium covered a news event.

radio waves. But it did start Taylor and Young thinking about using radio waves to detect moving objects.

Seven years passed. In June 1930, Laurence A. Hyland, a colleague of Taylor and Young, was experimenting with high-frequency radio direction finding. He detected a severe disturbance of the propagation field by an airplane flying overhead. Hyland was a Navy man and sensitive to the threat that aircraft posed to ships in wartime. Again, the application was obvious. He proposed that high-frequency radio be used to warn against approaching aircraft.

In January 1931, the Naval Research Laboratory (then known as the Navy's Aircraft Radio Laboratory) in Washington, D. C., set up a project for the "detection of enemy vessels and aircraft by radio." It was years before even the principles of radar were fully understood and implemented. In simplified form, they might be stated as follows:

- Electromagnetic radiation at high radio frequencies is used to detect and locate remote reflecting objects.
- The radiation is sent out in pulses of a few microseconds' duration, separated by intervals many times the duration of each pulse.
- The pulses are returned from the reflecting objects, and the returns are detected and displayed by receiving equipment placed at the point of transmission.
- The distance to the objects is determined by measurement of the time it took the pulses to reach the targets from the transmission equipment and return to it.
- The directions of the targets are determined by use of highly directive radio antennas.

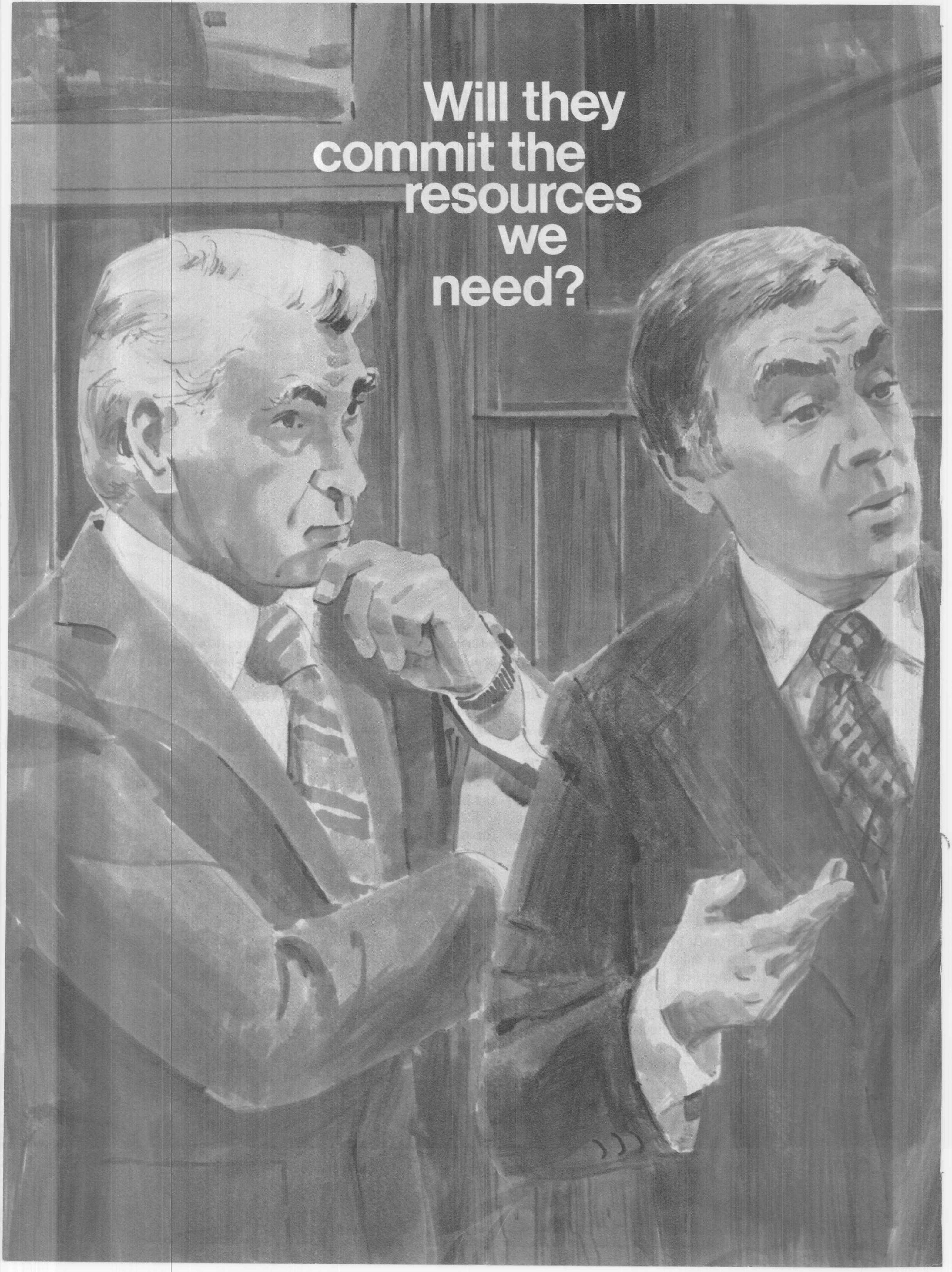
While no one person did all these things, the gradual implementation of them all by contributors both in this country and abroad is generally conceded to have led to the first radar.

Radar leaned heavily on certain contemporary devices for its development. The most important, the cathode-ray tube, became generally available as a laboratory tool in the early 1930s. And, of course, radar would not have been possible without the vacuum triode.

At the U. S. Naval Research Laboratory, the radar researchers investigated the "beat" method. In this approach the transmitter and reciver were widely separated and shielded from each other. Continuous-wave transmission was used, and at the receiver the fluctuating signals, called "beats," were observed when an airplane flew through the radio propagation field. A range of 40 miles was obtained.

The wide separation of transmitter and receiver required for proper operation precluded the use of the beat method on ships. Its usefulness was therefore limited to the protection of large land areas, such as cities and military bases.

Since this was the Army's responsibility, the Navy shunted its findings to that branch in January 1932. Navy interest flagged. Then Young suggested to Taylor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commit the
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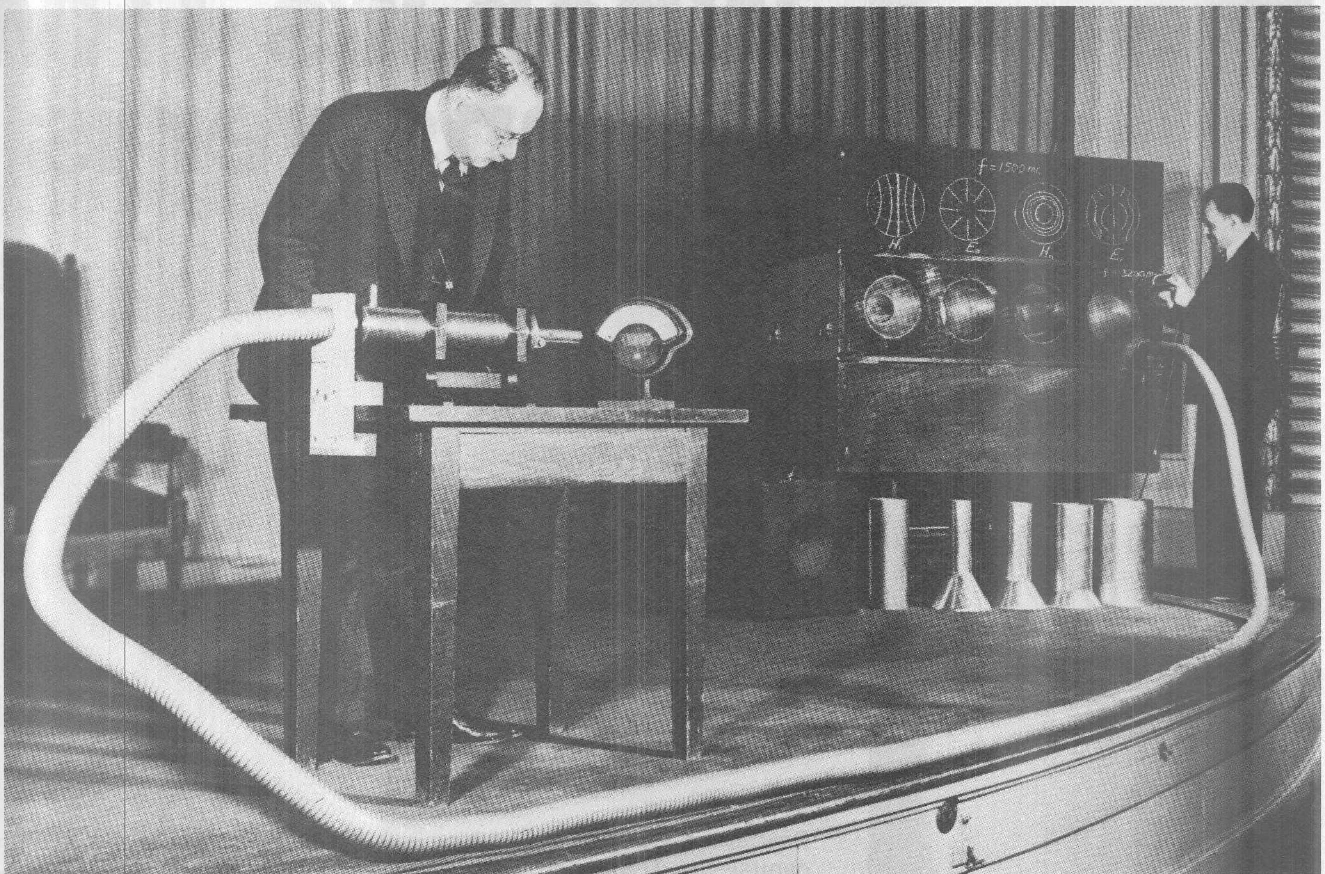
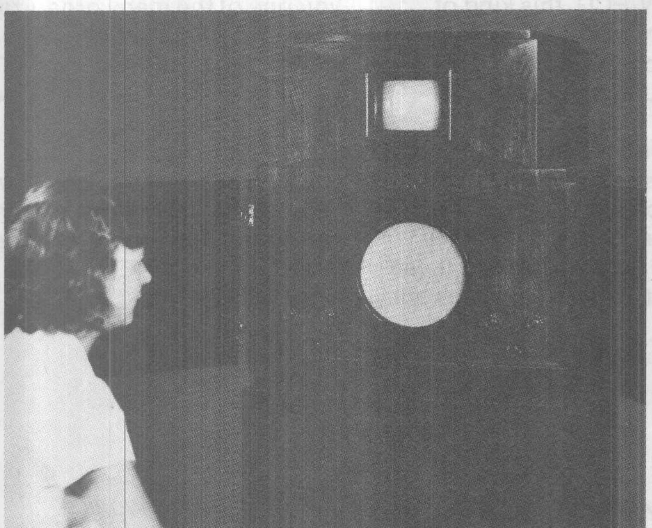
we
need?



Guide. The work of Bell Telephone Laboratories' George Southworth represented a new way of thinking about radio waves. This photograph was taken at the first public demonstration of waveguide transmission before the Institute of Radio Engineers on Feb. 2, 1938.



Big screen. Telefunken TV receiver, atop loudspeaker at 1932 Berlin Radio Show, was 9 by 12 cm, had 90 lines, 25 frames per second.

that the pulse method should be tried. Work on this approach was started in 1934.

The first step was to develop an indicator to display the transmitter and receiver outputs. A suitable sweep circuit was built for a commercial cathode-ray oscilloscope. The next step: a pulse transmitter. The transmitter frequency of 60 MHz was chosen because that had been used in the beat experiments. The antenna was a single resonant reflector. The pulse power was estimated at 100 to 200 W.

The next question was: could echo pulse energy be detected during the intervals between transmitted pulses?

A broadband, high-gain experimental communications receiver was borrowed and connected to a second antenna, similar to the transmitting antenna. When a small airplane flew across the beam at a distance of about a mile, the echo of the transmitted pulse caused the receiver output meter to fluctuate "violently," to quote one observer, between zero and saturation. It was evidence that echo signals could be detected during the intervals between transmitted pulses. Development of a practical radar receiver got under way immediately.

Radar imposed certain severe requirements on the receiver that were not encountered in conventional radio receivers of the time. Close proximity of receiver and transmitter subjected the receiver to heavy overload, and recovery to full sensitivity was essential in the incredibly short time of a few microseconds.

A second requirement was to minimize the time the receiver would oscillate, or ring, in response to the strong echo to the transmitter's high signal level. Researchers did this by redesigning the vacuum-tube amplifier circuitry and limiting the level to which the circuits could be driven by the transmitter.

A third requirement was for fast response by the receiver to amplify the short pulse echoes. This meant

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COMMUNICATIONS PRODUCTS

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QUADRASYNC/C™
(4-LINE DL11 REPLACEMENT/CL)

INSTALLS IN: All PDP-11's; 4-lines per SPC slot at one unit load to Unibus. **DATA RATES:** 7 independently selectable baud rates for each of 4 channels (150-9600). **ELECTRICAL:** 20MA current loop (Send : Receive). **VECTOR/ADDRESS SELECTION:** Vector and address values to be set on boundaries of 00₈ or 40₈. 16 continuous word address for Vector or Address.

QUADRASYNC/E™
(4-LINE DL11-E REPLACEMENT)

INSTALLS IN: All PDP-11's; 4-lines per SPC slot at one unit load to Unibus. **DATA RATES:** 7 independently selectable baud rates for each of 4 channels (150-9600). **ELECTRICAL:** EIA standard RS232C – with modem control. **VECTOR/ADDRESS SELECTION:** 16 continuous word address for Vector or Address – starting values selected on any boundary.

QUADRASYNC/LSI™
(4-LINE DLV11 REPLACEMENT)

INSTALLS IN: LSI-11 and PDP-11/03; 4-lines/card at one unit load to Unibus. **DATA RATES:** 8 independently selectable baud rates for each of 4-channels (110-9600). **ELECTRICAL:** 20MA active/passive current loop (Send : Receive) – also supports EIA standard RS232C. **VECTOR/ADDRESS SELECTION:** Like DLV-11 – 3-channels must have contiguous addresses and 1-channel may be set to any address including console address.

QUADRACALL™
(4-LINE DN11 REPLACEMENT)

INSTALLS IN: All PDP-11's; 4-lines per SPC slot at one unit load to Unibus. **PERFORMANCE:** Interfaces up to 4 Bell 801 ACU's with Unibus enabling any PDP-11 to dial any DDD network number to establish data link. **INPUT/OUTPUT:** 5-input signals from ACU are handled by EIA RS232 receivers. 6-output signals are transmitted using EIA RS232 drivers. **VECTOR/ADDRESS SELECTION:** Allows selection of device address and vector by use of pencil switches.

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(16-LINE DV11 REPLACEMENT)

INSTALLS IN: All PDP-11's; in less than one half the space of DV11. **DATA RATES:** 16-line throughput of up to 76,800 char/sec (19.2K baud full duplex for each line) total. **PROCESSING ADVANTAGE:** Word transfers (in lieu of byte DMA) permit user to operate within one half the DV11 bandwidth for data transfers. **OPERATING ADVANTAGE:** User may mix sync and async lines in combinations of 4 or 8 lines with modem control and full system software compatibility with all DV11 performance features.

MEMORY PRODUCTS

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CACHE/434™
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INSTALLS IN: PDP-11/34 and -11/34A **without** using any additional backplane space! **CAPACITY:** 8192 byte (4K word). **ENHANCEMENT FACTOR:** Run time reductions to 40% (70% speed improvement) are achievable. **CACHE PARITY:** Automatically goes off-line in event of any data or address error. **RANGE SELECTION:** User may optimize hit ratio by upper/lower limit switch settings. Cache action monitor indicates hit rate.

CACHE/440™
(4K WORD CACHE MEMORY)

INSTALLS IN: PDP-11/35 and -11/40 **without** using any additional backplane space! **CAPACITY:** 8192 byte (4K word). **ENHANCEMENT FACTOR:** Run time reductions to 40% (70% speed improvement) are achievable. **CACHE PARITY:** Automatically goes off-line in event of any data or address error. **RANGE SELECTION:** User may optimize hit ratio by upper/lower limit switch settings. Cache action monitor indicates hit rate.

EMULOADER™
(ODT/BOOTSTRAP LOADER REPLACEMENT)

INSTALLS IN: PDP-11/05, -11/10, -11/35, -11/40, -11/45, -11/50 and -11/55. **MECHANICAL:** Dual width card replaces standard Unibus termination; requires no additional backplane space. **OPERATING ADVANTAGE:** Provides fixed console emulator (ODT) and bootstrap loaders for DL11, PC11, RF11, RK06, RK11, RP04/05/06, RP11, RS03/04, RX11, TC-11, TM11 and TU16. **SPECIAL FEATURE:** Performs memory diagnostic each time a boot operation is done from ODT.

GENERAL PURPOSE PRODUCTS

QNIVERTER™
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INSTALLS IN: LSI-11, LSI-11/23, PDP-11/03 and PDP-11/23 via quad-width card. **APPLICATIONS:** Allows Unibus-compatible controllers and memories to be used with LSI computer systems, or LSI-based peripherals to be used with PDP-11 computer systems. **FEATURES:** Supports features of LSI-11/23 including the full 128K address capability.

REBUS™
(BUS REPEATER – DB11 REPLACEMENT)

INSTALLS IN: All PDP-11's; **without** using any additional backplane space. **MECHANICAL:** One dual-width card plugs into the same pair of connectors as the Unibus extension cable which is then plugged into the REBUS connectors. **COMPATIBILITY:** Allows for 18 additional bus loads and 50 foot bus extension. Requires no software changes. Bus cycle time unaffected for devices on CPU side of REBUS – increased by 250 nsec max. for devices on outboard side.

DUAL I/O™
(GENERAL INTERFACE-DR11-C REPLACEMENT)

INSTALLS IN: All PDP-11's; in any SPC slot via quad-width card. **APPLICATION:** Dual I/O is equivalent to two (2) DR11-C's and provides the logic for program-controlled parallel transfer of 16-bit data between two (2) external user devices and a Unibus system. **OPERATING ADVANTAGE:** Provides user the hardware/software equal to a dual DR11-C in one-half the space and one-half the bus loading of DR11-C's.

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Discovery. A. Hoyt Taylor (with pipe) and Leo C. Young observed that a ship on the Potomac interrupted the signal between their high-frequency transmitter and receiver.

tailoring the tuned circuits so that the receiver characteristics would match the pulse-transmitting properties.

Finally there was a need for complete absence of regenerative feedback in the receiver in the presence of high gain. Researchers met this by using a superheterodyne receiver, limiting voltage gain on any one frequency to 1,000, and changing the intermediate frequency, as required, to accomplish an overall voltage gain on the order of 10^7. Also, extreme precautions were taken in shielding, filtering, and common-point grounding.

The new Navy system was ready for full-fledged testing in April 1936. Receiver recovery to full sensitivity following the transmitted pulse seemed instantaneous, and beautifully sharp echoes from aircraft were observed almost at once. Within a few days the echoes appeared all the way to the 25-mile limit of the indicator.

The success of this experiment was followed by a greatly intensified effort at the laboratory. Of course, the primary objective was to reduce the size of the equipment so it could be used on ships. This meant higher frequencies and smaller antennas. This was done, and on July 2, 1936, a small radar was put into operation on 200 MHz. In that same month the first radar duplexer was successfully tested, also at 200 MHz. This enabled both transmitter and receiver to use the same antenna. These two quick developments made it possible to put radar on a ship for tests at sea.

The first seagoing radar tests by the United States were made in April 1937 on the World War I destroyer, the USS Leary. Their success led to the development of the model XAF, designed for Navy service at sea. Extensive shipboard tests in 1939 disclosed operational capabilities beyond all expectations. The XAF later became the prototype for the model CXAM, which was put in service on 19 ships. It was the only U. S. naval radar in service when Pearl Harbor was attacked.

As is usual in such matters, because of the way science is done, interest in the radar concept developed in Europe at about the same time (1934) as in the U. S. In Britain, for example, as in the U. S., the work was based on earlier endeavors in 1924 and 1925 that had used high-frequency radio waves to measure the height of the Heavyside layer—a region of the atmosphere that reflects radio signals.

Although in 1939 England, Germany, and the U. S. were the leaders in radar development, it was actually the French who made the first commercial application of it in 1935. What they did was both clever and useful.

Scientists of the Société Française Radioélectrique had the rescue of the shipwrecked in mind when they began studying the detection of obstacles by means of radio waves in 1934. As a result, an obstacle detector working on decimetric waves and employing pulsed magnetrons was installed on the liner Normandie in 1935. Its satisfactory performance led to a search radar being installed at Le Havre in 1936 to detect ships entering and leaving the harbor.

The reflection of radio waves from aircraft had been observed in England in the early 1930s and the possibility for aircraft detection was discussed in 1934. It was soon realized that radio waves would be the ideal alternative to the existing inadequate acoustic warning equipment, which merely listened for the sound of aircraft engines and had too short a range for proper warning of approach of fast aircraft. In contrast, experiments indicated that radar could give a warning when the enemy aircraft was 100 miles or more away.

Robert (later Sir Robert) A. Watson-Watt, who began as a physics teacher at University College, Dundee, was instrumental in developing radar equipment for this purpose in Britain. His Radio division of the National Physical Laboratories was the leading group involved. After successful demonstrations of his approach in early 1935, he was given funds to start production and in the summer of the same year installed the first practical radar for aircraft detection.

How to modulate his high-power transmitter with short pulses was the major practical problem for him as it was for the Americans. He solved it, and the performance of the first equipment was so good that by the end

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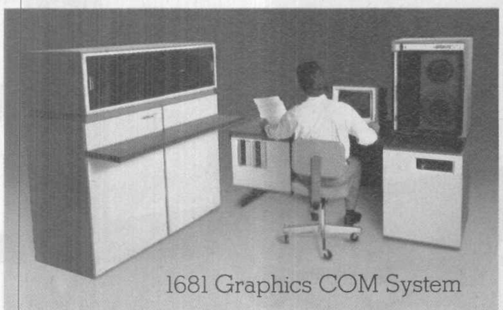
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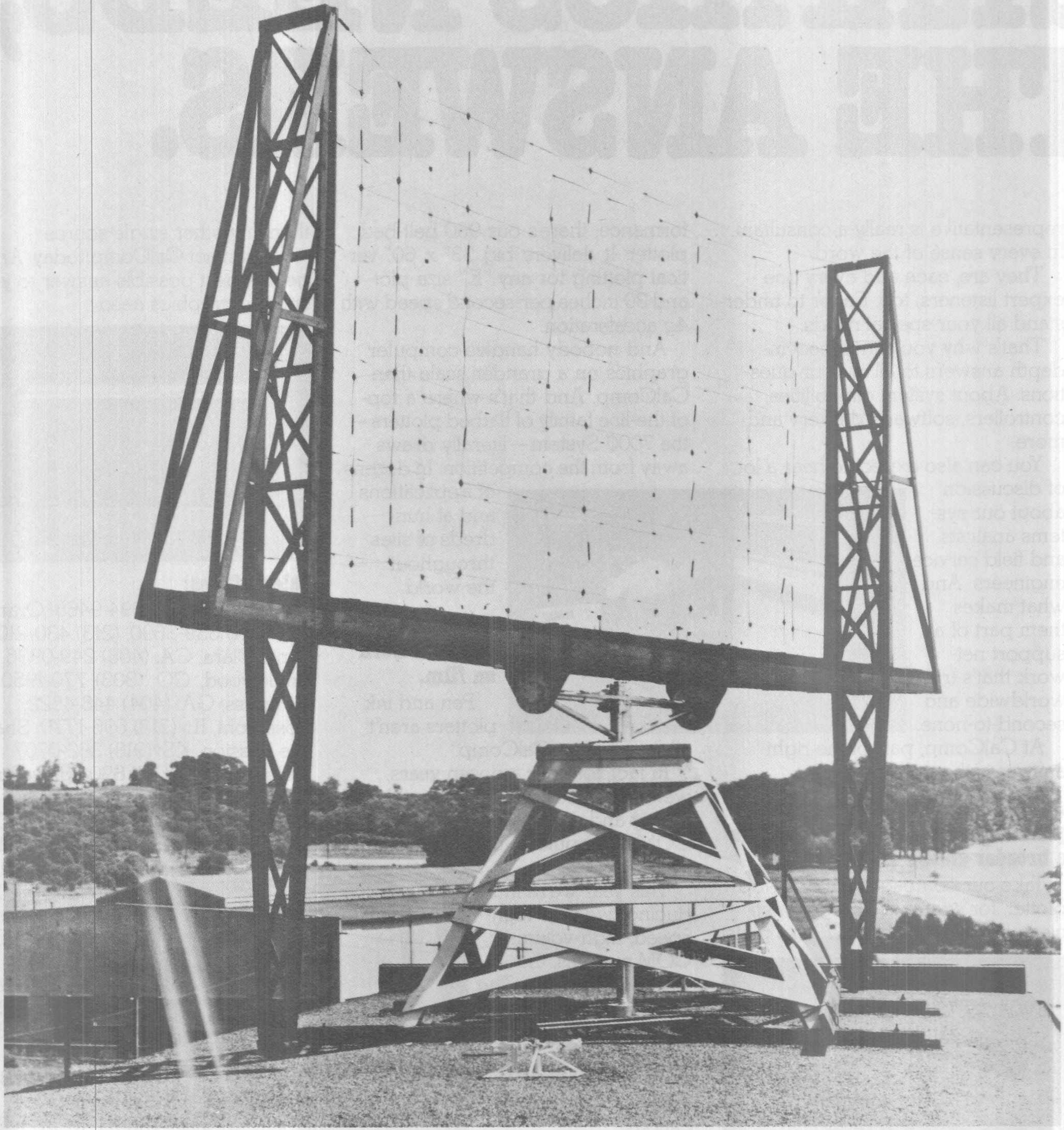

Radar. Antenna for first complete radar in the United States was installed atop building at Naval Research Laboratory, Anacostia, D. C., in late 1930s. It was called a "dirigible" antenna, to indicate that it could be turned in an around-the-compass search.

of 1936 the Air Ministry had built a chain of five radar stations about 25 miles apart. This would later play a crucial role in the Battle of Britain, when British fighter planes were vectored to the location of the German aircraft by the use of radar search data.

Serendipity, that happy circumstance that so often comes into play when inventors and experimenters work, did more than speed the development of radar in the United States. It was of enormous help also in advancing electronic instrumentation in the 1930s. Early attempts to transmit pictures by radio waves in the same manner as sound led, for example, to the development of the modern oscilloscope. And it could not have come at a better time.

The oscilloscope had progressed considerably since Karl Ferdinand Braun used a cathode-ray tube to observe time-varying phenomena in 1897 at the University of Strassburg, then in Germany. Braun is generally

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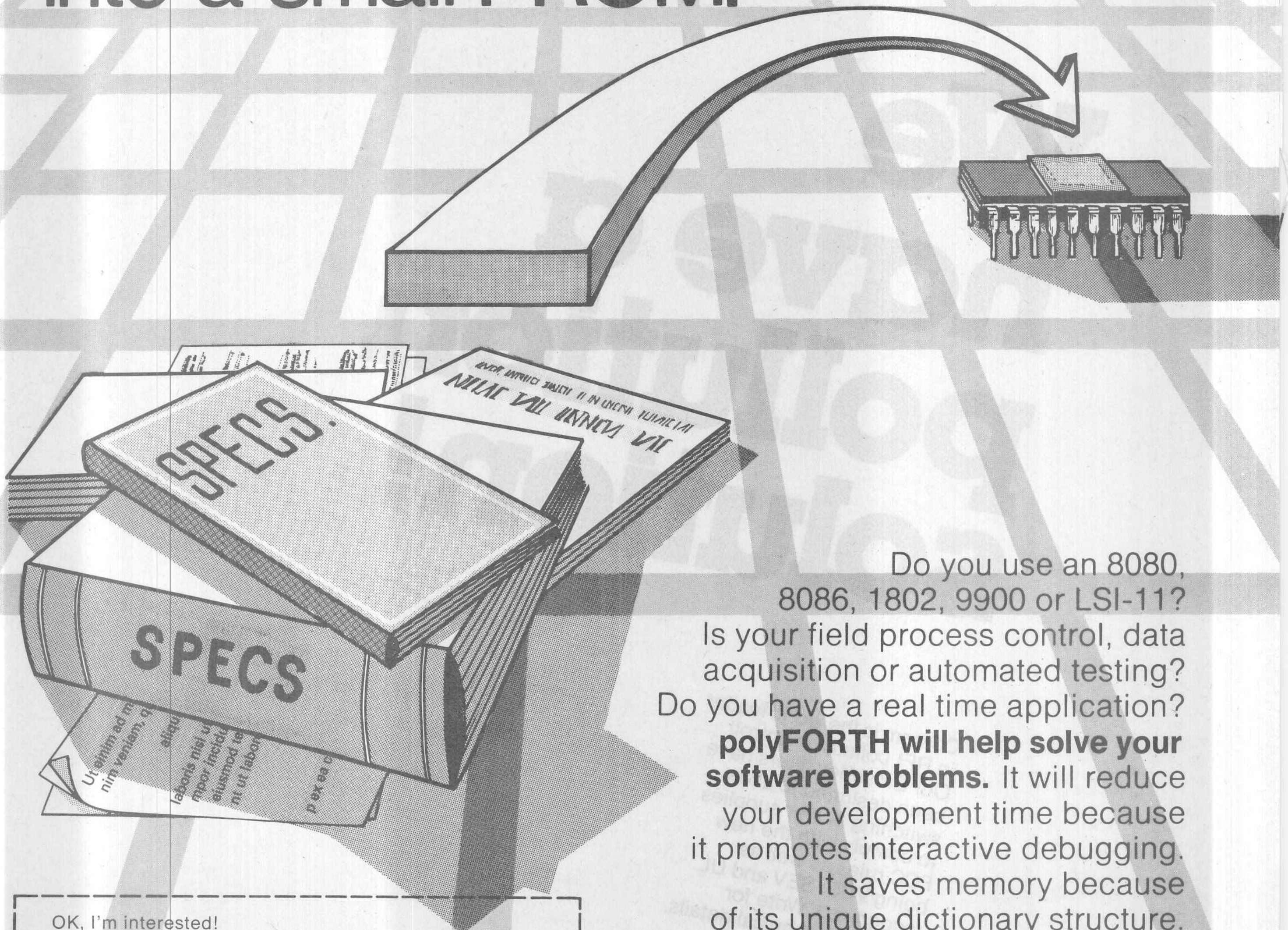

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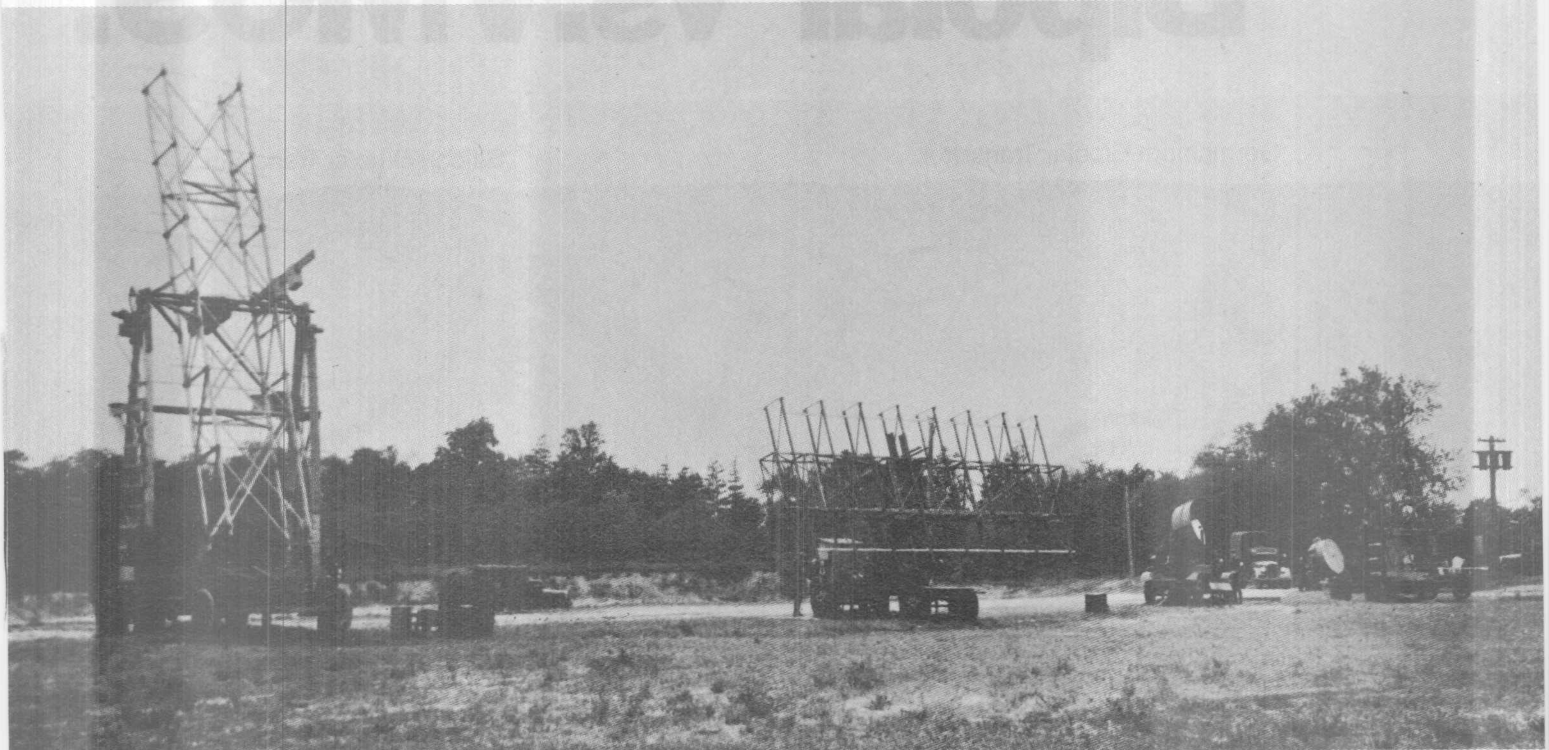


Early radar. The U. S. Army demonstrated an experimental long wave antiaircraft position-finding radar, the SCR 268, in May 1937 at Fort Monmouth, N. J. Used in World War II, the radar was easily jammed by window, or chaff. The later microwave SCR 584 was more effective.

credited with having invented the device, but his CRT was of use only in the laboratory. If engineers had had to rely on such an instrument, the history of electronics would probably have advanced no further than the radio.

In the early 1930s a change was taking place in the art of electronic measurement. Engineers began to realize that to characterize the operation of equipment fully, they could not look only at the steady-state operation of a system; they had to observe its transient response as well. While there were already various oscillographs of the galvanometric type in use (Bell Telephone Laboratories had more than 100 such oscillographs in constant use in 1931), these instruments could not keep pace with the high frequencies that radio transmission involved. Enter serendipity.

Many experimenters were trying to improve the cathode-ray tube so it could be used to display photographs. Manfred von Ardenne of Berlin had produced what was considered a low-voltage tube, and General Radio Co. used a tube of this type to produce a cathode-ray oscilloscope in 1931. It consisted of two parts: a cathode-ray tube, housed in a cylinder to protect it from ionic bombardment, and a cabinet containing focusing controls. It provided signals visible in daylight during the 1,000-hour life of the tube, and at $265, it was considered relatively expensive.

But it was Allen Du Mont who was largely responsible for the commercial development of the modern oscilloscope. Between 1930 and 1931, he left his position as chief engineer at the De Forest Radio Co. to open the Allen B. DuMont Laboratories, where, in addition to consulting on television, he designed cathode-ray tubes. In August 1932 he advertised these tubes, and in November of that year he offered his first oscilloscope—or "cathode-ray oscillograph," as he called it. A two-part unit like General Radio's rudimentary oscilloscope, it had in its electronics cabinet both focusing controls and a power supply and sweep circuit. It sold for $185.

In 1933, Du Mont continued to improve CRT design, particularly the low anode potential, screen materials, and beam intensity. In July of that year he introduced a single-unit oscilloscope with a sweep frequency of 10 to 5,000 Hz. This large instrument was intended for the laboratory only, however.

But in January of 1934, Du Mont introduced the model 137, and it was clearly what is termed today an oscilloscope. An engraved glass on the screen provided lines for measurement, and the front-panel knobs permitted continuous adjustment of sweep and focus. The unit operated from an ac line, sold for $165 and had a handle on top for easy carrying.

Through the remaining 1930s Du Mont continued to improve the oscilloscope. It became a workhorse for engineering measurements, with new applications suggested for it almost monthly.

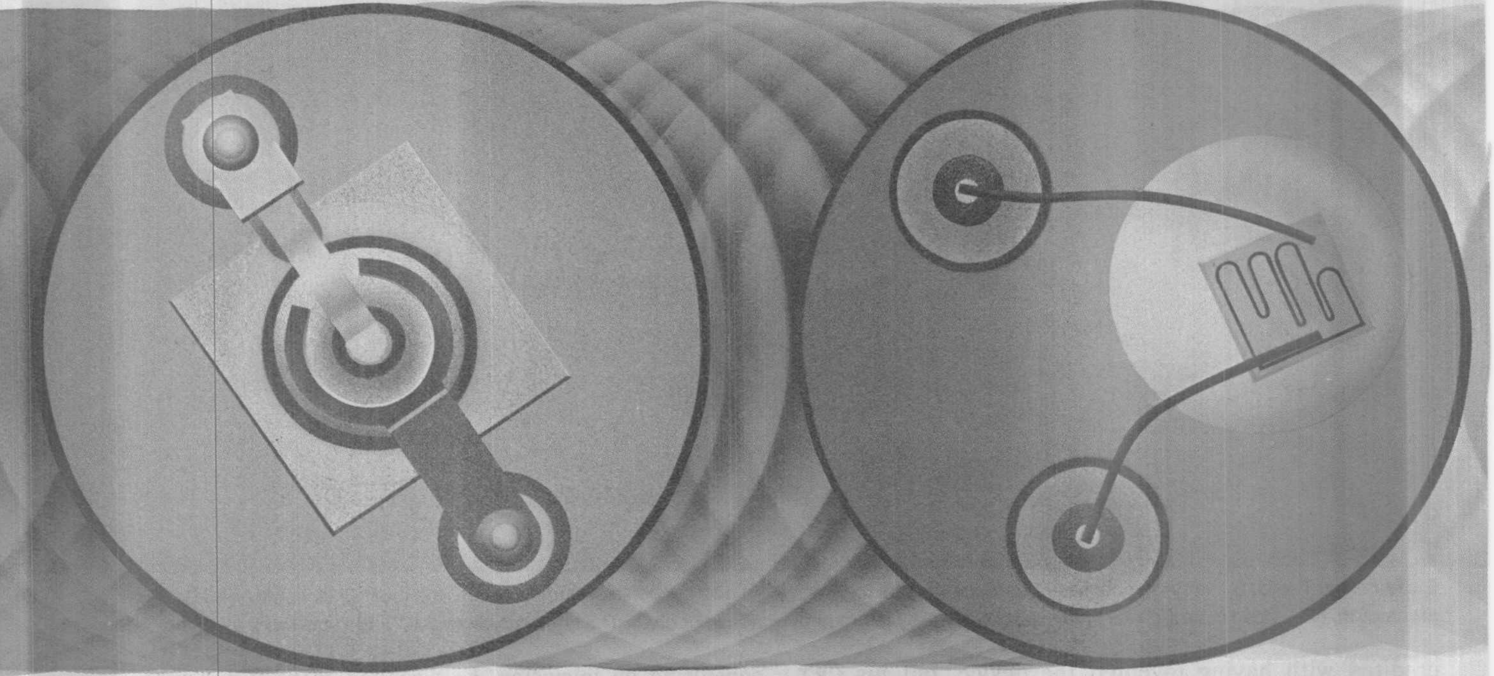
In the spring of 1935, RCA introduced its oscilloscope, the forerunner of a line of instruments for service technicians as Du Mont's oscilloscope was for the engineer.

Vacuum-tube voltmeters were another success story. The high-input impedance of vacuum tubes had made them natural candidates for instruments since they were first developed. This characteristic suggested that they could be used to make measurements without putting any effective load on the circuit under test. But while the

Bipolar vs. VMOS:

Germanium Bipolar Transistor

Silicon Bipolar Transistor



It's survival of the fittest

The designers who are going to survive the fiercely competitive 1980's know bipolar technology is dead. That's why they're switching from bipolar transistors to vertical current flow FETs for power and for microprocessor interface in power applications. It's the switch you should make now, before it's too late.

Look at the facts. Germanium power transistors were first introduced in the early 1950's. Then, in the late 50's, silicon took over. Silicon bipolar transistor reliability and temperature performance was remarkable... for the time. But that was over 20 years ago. And a lot has changed since then.

One of the most significant changes has been the unprecedented growth of MOS technology. You saw it happen with ICs. In just a few short years, MOS replaced bipolar ICs and revolutionized the entire semiconductor industry.

Then, in 1976, Siliconix introduced the first Vertical power MOS FET and launched the VMOS power FET revolution. Three VMOS generations and four years later, VMOS equals or exceeds bipolar performance in important operating characteristics. And, as VMOS technology is still on a rapid learning curve, you can be sure there's more to come.

What can VMOS do for you?

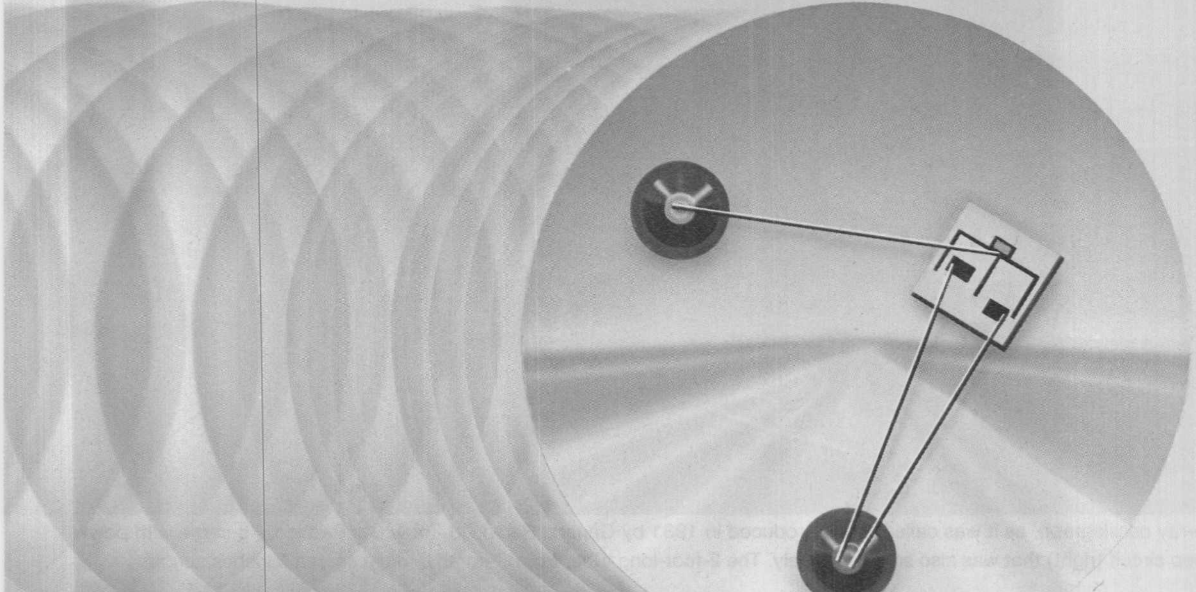
A lot. VMOS provides high power gain, high input impedance, linear operation and a full safe-operating-area. But even more important, VMOS offers you a new degree of reliability by eliminating the two most common causes of bipolar transistor failure: thermal runaway and secondary breakdown.

Use Siliconix VMOS instead of bipolars and you eliminate the predrivers and protective circuitry bipolar transistors require. Fewer parts mean lower costs and higher overall system reliability.

And, as they don't require the high base current drive bipolar transistors do, VMOS power FETs are ideal for interfacing to low power ICs.

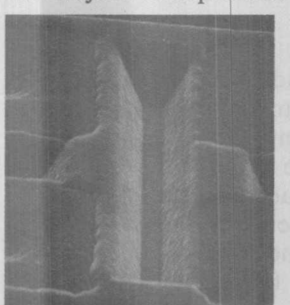
Siliconix VMOS

The winner emerges



Not just rugged, but faster too

VMOS devices switch in nanoseconds with comparable turn-on and turn-off times which you can adjust independently. This allows you to improve the efficiency of switching circuits, extend the frequency response of power control systems and even build rf power circuits. So, whether you're driving bubble memories, building power circuits or interfacing CMOS logic, you can put the advantages of VMOS to work for you.



VMOS FET magnified 2300x.

Price? Glad you asked

True, in the early years, VMOS cost more than bipolars. But that's all changing today. Economies of volume production have substantially reduced the cost of VMOS. Additionally, as VMOS so dramatically reduces your component count and simplifies your designs, your big savings will be in overall system cost.

Join the Survivors

When you look at the facts, you can see it's only a matter of time. Bipolars can't survive. But you can. With Siliconix VMOS on your side in the 80's.

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VMOS power FETs

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Scope. The cathode-ray oscillograph, as it was called, was introduced in 1931 by General Radio Co. (now GenRad Inc.). It came with power supply (left) and sweep circuit (right) that was also sold separately. The 2-foot-long tube, from Germany, had a screen 6 inches across.

vacuum tube was being used in measurements even before 1930, J. W. Horton, chief engineer at General Radio Co., noted in the first issue of *Electronics* that the tubes lacked "that stability and consistency of performance so generally considered essential to successful measuring equipment." When used in instruments, the vacuum tube had to be calibrated against a standard voltage reference before each measurement.

In January 1931, Ballantine, then president of the Boonton Research Corp., discussed the variable-mu tetrode that he and Snow had unveiled at the end of the previous year. He noted that the tube's logarithmic response should be ideal for many measurements.

While improvements like these were essential to the development of reliable instrumentation, it was the discovery of a startlingly simple principle—negative feedback—that made possible stable measurements.

Black at Bell Telephone Laboratories had discovered that part of an amplifier's output could be returned to its input in such a way as to prevent unwanted gain or loss of output. But it was not until he presented a paper early in 1934 to the American Institute of Electrical Engineers and then wrote an article for Bell Telephone in June of that year that engineers became fully aware of this important principle.

By the late 1930s Ballantine had opened his own laboratory and begun to produce an instrument that was to make the phrase "hand me the Ballantine" part of engineering jargon for the next four decades. In the September 1938 issue of *Electronics*, he described this root-mean-square meter, the model 300, noting that "it is about 100 times as sensitive as the conventional electronic voltmeter, permitting readings down to 0.001 V."

Off-the-shelf precision instruments were still relatively rare. Engineers generally built their own. The pages of the early issues of *Electronics* are filled with "how to" articles. For production testing, for example, articles told how a tube tester could be constructed with meters from Weston, Westinghouse, or GE wired into a panel that contained switching arrangements. Similar articles dealt with the design of oscillators, signal generators, and other essential equipment.

One radio-related instrument that manufacturers were quick to offer was the tube tester. It was sold to radio merchants so they could check tubes for customers. Keeping pace with the flood of new tubes that arrived during the decade kept the manufacturers of tube testers busy. Each new tube type called for an addition to the tube tester. And these testers served not only the radio era but also the era of television, which was unfolding.

Matching the relentless advances of radio were frequency standards. Those that employed tuning forks were in common use at the beginning of the 1930s and were accurate to within 1 part in 10^7. But although they were highly stable, they had the disadvantage of operating at frequencies of only 1,000 Hz. Thus it was difficult to make comparisons with the higher frequencies of radio transmission.

On the basis of the work of W. Gady, who had noted the stabilizing effect of quartz crystals on the oscillations of vacuum-tube circuits, J. W. Horton and W. A. Marrison developed the first crystal clock, which they described in a paper in the February 1928 Proceedings of the Institute of Radio Engineers. But it was not until May 1930 that the first quartz clocks were installed at

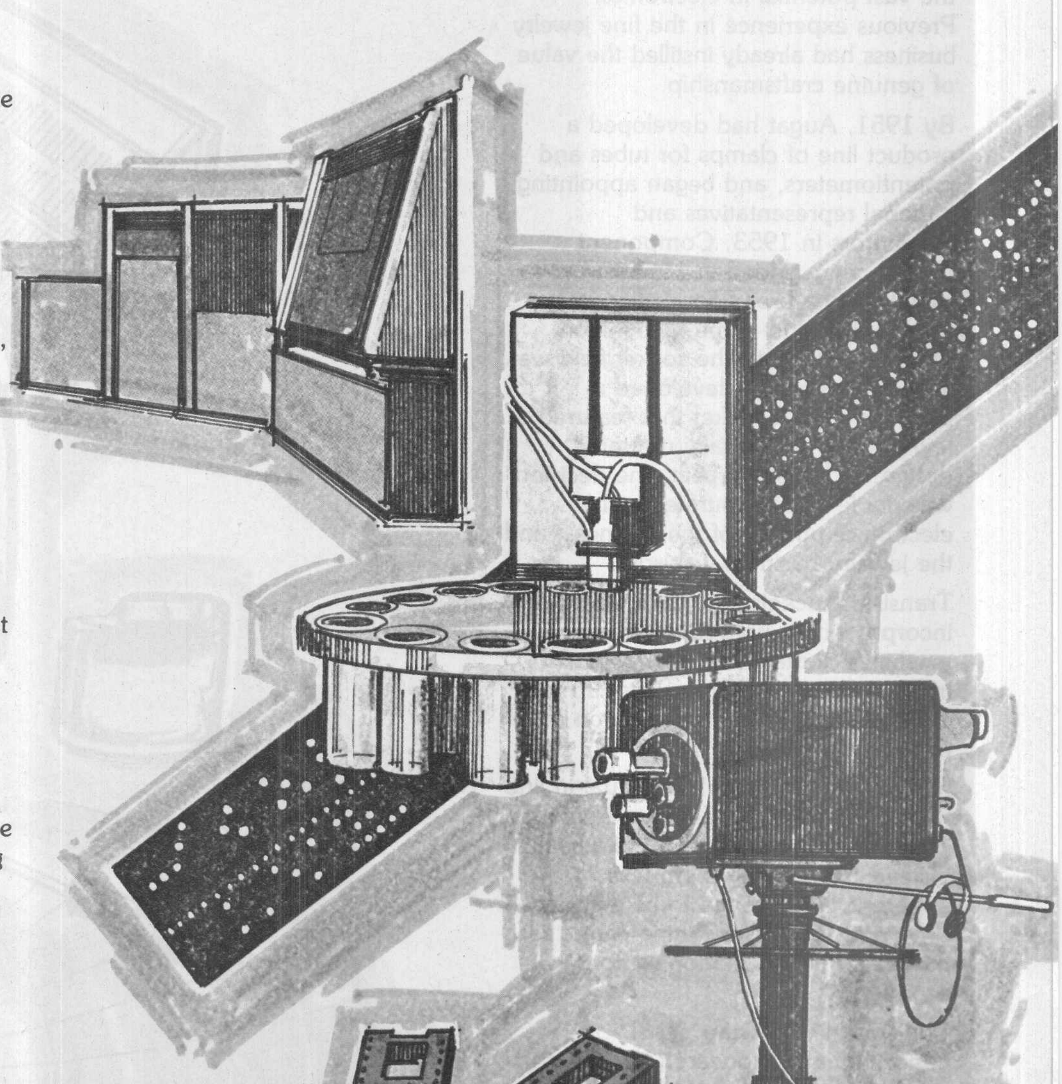
You'll find AUGAT products in the darndest places...

You'd expect to find Augat products in typical computer and peripheral systems. But you might not realize the full breadth and diversity of Augat's applications and markets.

Upon close examination, you'd find "Augat" in the local hospital, or at your favorite television station...or in your neighborhood bank...even on the moon!

And that's because the name "Augat" has become synonymous in the electronics industry with words like "quality" and "dependability" and "innovation". In the brief thirty years we've been producing electronic interconnection products, Augat has become known as the industry's trailblazer.

In 1931, Ernest Augat founded Augat Brothers, a manufacturer of jewelry and jewelry findings in Attleboro, Massachusetts. At the start of World War II, much of the raw materials used to manufacture jewelry were allocated to military use, but Augat's machinery and skilled employees were admirably suited to the manufacturing of stamped component parts for the military electronics industry. Augat quickly became a subcontractor for companies engaged in the war effort.



At the end of hostilities, Augat returned to the jewelry business, as Augat Inc. But, in 1950, at the onset of the Korean conflict, the company again began manufacturing electronic components.

Augat management soon recognized the vast potential in electronics. Previous experience in the fine jewelry business had already instilled the value of genuine craftsmanship.

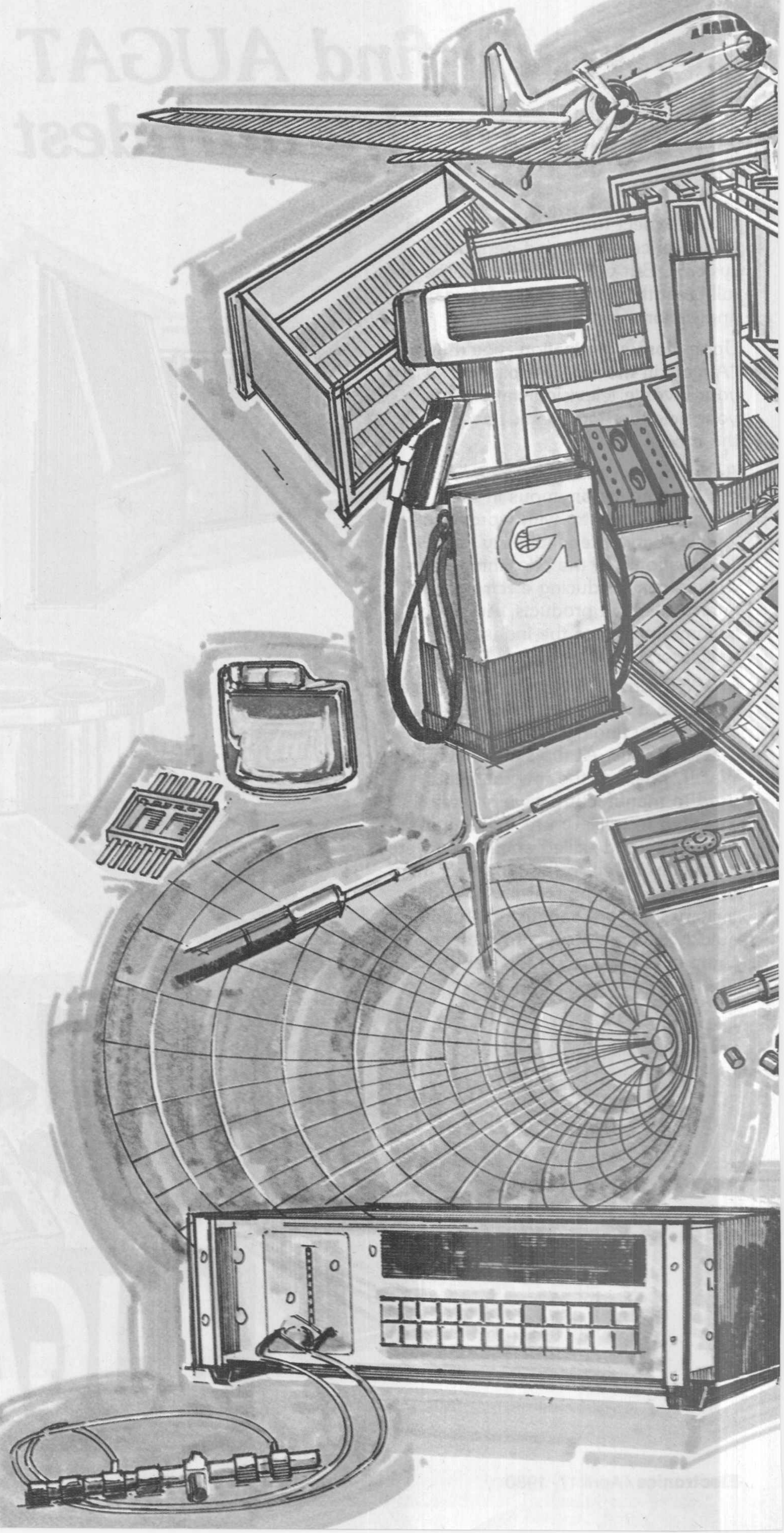
By 1951, Augat had developed a product line of clamps for tubes and potentiometers, and began appointing national representatives and distributors in 1953. Component holders were added in 1955, establishing a broad base of applications and name recognition. Our first entry into the socket field was in 1958, when we developed a patented crystal socket that featured a low-profile, horizontally mounted design. In the same year, the decision was made to concentrate on the electronics portion of the business, and the jewelry business was sold.

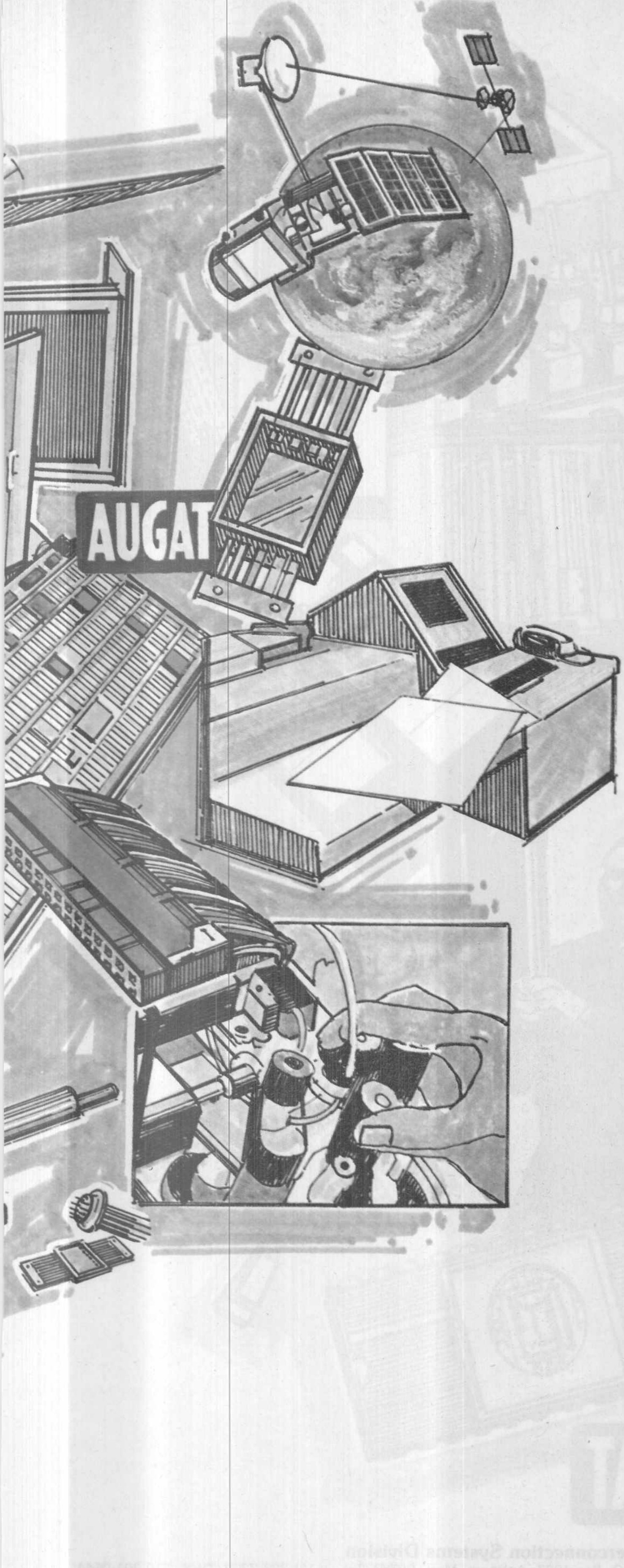
Transistor sockets soon followed, incorporating a unique two-piece machined contact assembly. Circular integrated circuit (IC) sockets, up to 12 pins, were a logical extension of this approach.

In 1964, the industry's first dual-in line IC socket was introduced by Augat. The need to plug circuits into a socket instead of soldering them was apparent, and proved to be a strong driving force in establishing Augat as the leader in IC interconnection products.

The socket wire-wrap panel, conceived and pioneered by Augat in 1965, was a timely solution to users' problems of flexibility, design changes and density. After evaluating all cost factors including time, it even proved to be cost-effective for volume production applications. That same year, Isotronic high reliability, all metal packages were introduced for protecting hybrid and other miniature circuits through hermetic sealing.

Our new adaptor plug that allowed other components to be plugged in followed in 1966. About the same time, the interfacing plug was introduced, greatly expanding the flexibility.





1967 saw the introduction of the high performance 500 Series Socket.

In 1970, the hi-density plug series was announced, doubling the number of input/output connections possible for each group of IC positions. And that same year, Augat introduced the innovative 700 Series Sockets, with their disposable carriers that allow for improved air-flow and total accessibility for inspection and solder rework.

Three-layer Schottky and ECL panels were introduced in 1972 for high-speed logic applications, offering the flexibility, time savings and density required for prototyping and production. The list goes on and on.

In 1976, Augat introduced a completely new type of industrial subminiature switch...the Alcoswitch TT Series, less than 60% the size of any previously available comparable product. That same year Augat began providing computer-aided design and automatic wiring services which today includes five United States locations.

When Augat introduced the zero-profile HOLTITE® socket in 1977, the industry was impressed, but hardly surprised. We had already clearly established our reputation for innovation and quality. Of course, HOLTITE® was a revolution in itself. Not only was it the first zero-profile socket, it even utilized existing printed wiring circuit boards, and eliminated soldering.

Also in 1977, we began expanding our product base to include more sophisticated data links; areas like Fiberoptics and Flat Cable Interconnection.

Fiberoptics first appears to be a departure from Augat's traditional product line, but it is in reality simply a different method of signal transmission. The major difference being that glass, instead of wire, carries the signals. So when Augat developed and introduced one of the first complete standard catalog systems in 1977, it was readily apparent to the industry that Augat's reputation for establishing standards would continue to be a strong reason for our successful growth.

And as far as flat cable interconnection is concerned, in 1979 Augat introduced what has been hailed by the industry as a totally new generation in mass-termination products; the SGF/SGH line. This revolutionary interconnection system virtually doubles the I/O portion of any panel, and provides total flexibility in any combination of signal and ground assignments. The SGF/SGH System makes flat cable interconnection more efficient and at the same time less costly by reducing the number of contact points required.

During the 1970's, Augat also increased its level of vertical integration, with the addition of high quality, high reliability capacity for plating (1972), precision component machining (1974), and plastic molding (1979). These capabilities are offered to the electronics industry through our Precision Materials Division.

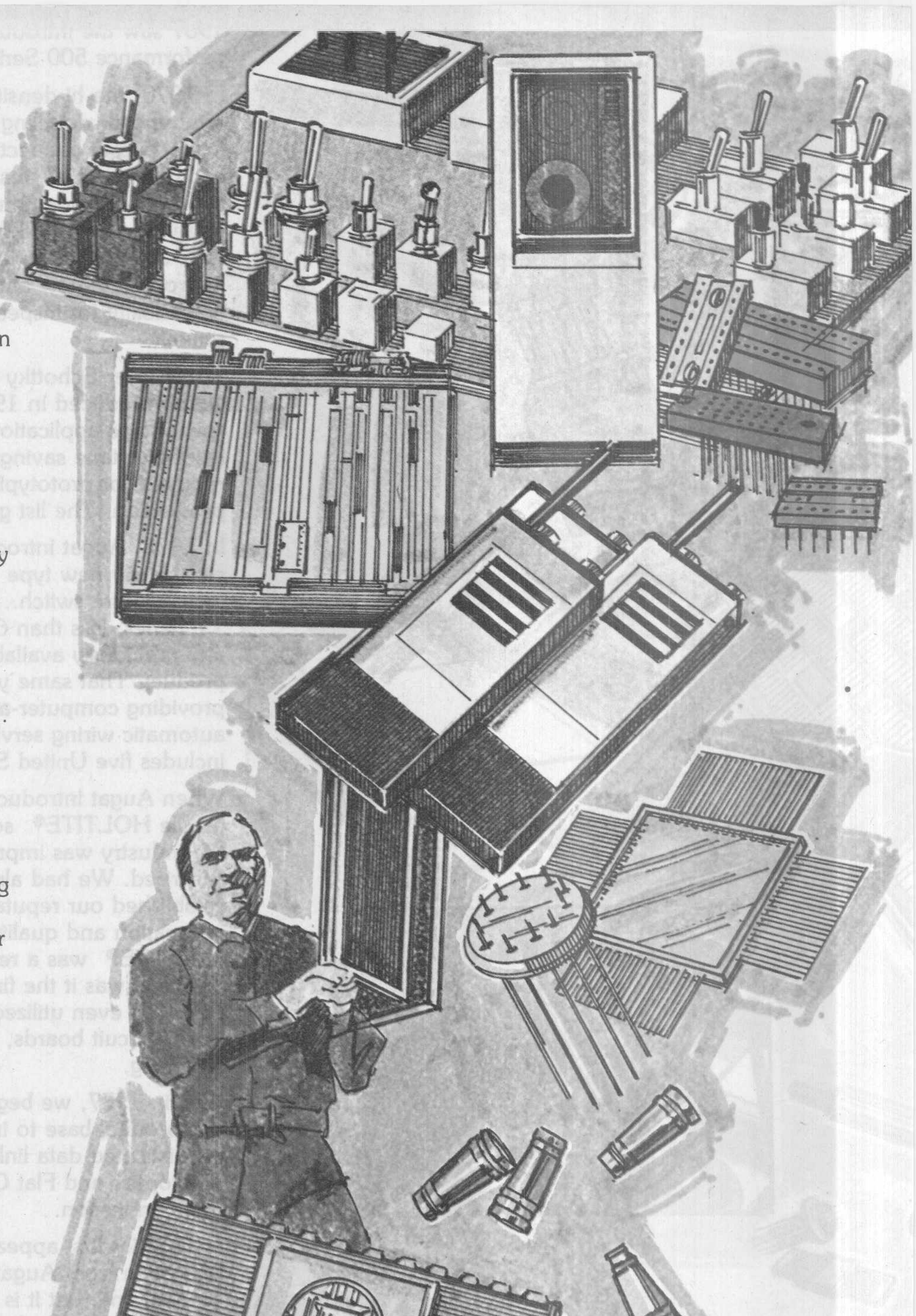
Today, Augat is a major supplier of interconnection components for the cable television industry through its subsidiaries, VITEK and LRC Electronics.

Applications for Augat products include videotape recording systems, heart pacemakers, mini-computers, typesetters, flight simulation systems, microwave transmission systems, textile machinery, and our microswitches were used in the first lunar lander.

Hand-in-hand with our innovative reputation goes the reputation we have for quality.

And everyone agrees that one of the most important keys to Augat's success is its distributor network. There's at least one franchised Augat distributor in almost every major city in the world.

And that's why you'll find Augat's products in the darndest places. Like your Uncle Pete's pacemaker and on the moon.



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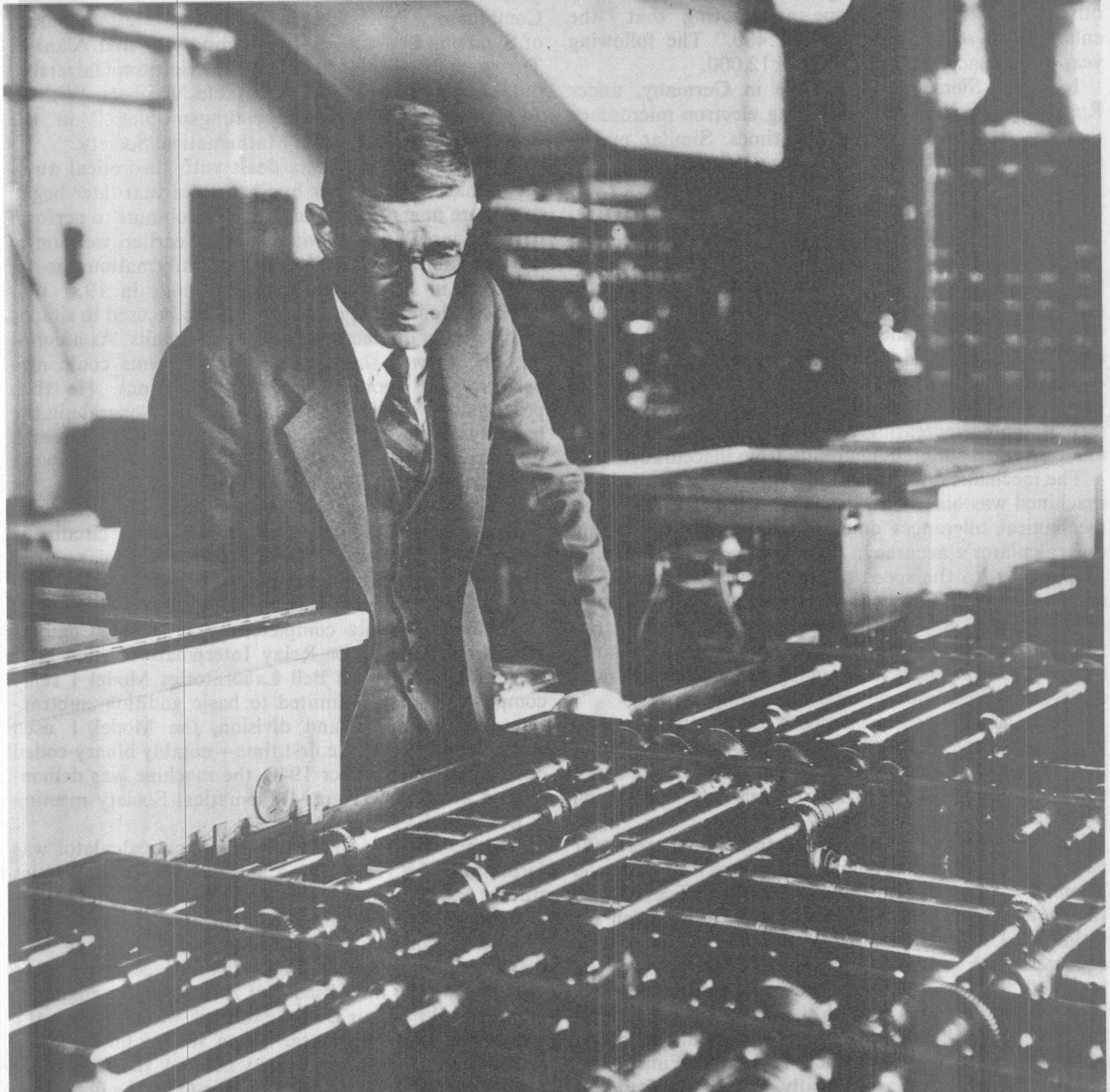


Analyzer. Vannevar Bush completed this differential analyzer in 1931 at the Massachusetts Institute of Technology. The analyzer was one of a series of Bush machines that were the precursors of modern analog computers. Their development stemmed from Bush's work on electric power transmission systems. He felt the need for machines that could perform analytical tasks too formidable for mathematicians alone.

the Federal Bureau of Standards in Washington, D. C. Throughout the 1930s other nations installed these clocks, and this led to an interesting discovery.

In Germany, at the National Physical Laboratory, the crystal clocks were used to time information to scientific and industrial laboratories. In 1934, after the clocks had operated for a year, the laboratory reported a discrepancy between diurnal and atomic time of 0.004 second that could only be accounted for by a change in the rotational speed of the earth.

And yet another scientific finding based on electronics led to the development of the electron microscope. The possibility of using electron beams to provide magnification with greater resolution than that of an ordinary microscope was postulated by M. Knoll and von Ardenne in 1930. Early in 1931, workers at the Technical University of Berlin and at the German Electric Co. noted that electrons emitted by a surface could be focused by coils to form an image of that surface. E. Breuche, H. Johannson, and R. Rudenberg constructed devices that could enlarge specimens about 15 times. But the first men to truly exploit the potential of electron microscopy were Knoll and E. Ruska.

In the September 1933 issue of *Electronics*, Knoll

published a paper explaining the operation of the transmission electron microscope and noting that "the enlargement so far attained is 1:400." The following year Ruska had improved this to 1:12,000.

In 1938, Siemens and Halske in Germany, under Ruska's guidance, built a scanning electron microscope that enlarged specimens 30,000 times. Similar microscopes were built at the College of Technology in London, with the help of the Metropolitan-Vickers Electric Co., and at the California Institute of Technology.

Throughout history, man's progress has stimulated a desire for improved computational tools. Electromechanical analog computers and calculators continued to be perfected through the 1930s, especially through the efforts of Vannevar Bush at the Massachusetts Institute of Technology. Nevertheless it was becoming increasingly evident that the mechanical analog devices suffered inherently from inaccuracy.

The mechanical tolerances to which the parts could be machined was one limitation. With use and wear, these mechanical tolerances deteriorated, further decreasing the calculator's accuracy. Accuracy was also inversely proportional to the speed at which the device could be operated. Finally the analog computers required human intervention to complete a calculation and were restricted by their design to solving a unique problem. Changing the problem involved changing the mechanical linkages—a cumbersome and time-consuming process.

While some researchers spent time attempting to improve the analog processor, others began exploring a new type of computing machine—one that would automatically follow a set of instructions and operate on more accurate discrete values.

The pursuit of more exacting astronomical tables for navigation prompted Columbia University to persuade Thomas J. Watson, the chief executive officer of the International Business Machines Corp., to establish the Columbia University Statistical Bureau in 1929. It was equipped with tabulating machines manufactured by IBM and then in use in the business world. In 1930, Watson was so impressed with the success of the Columbia laboratory that he authorized it to build a special tabulator called the Difference Tabulator. Finished in 1931, the machine was basically a digital calculator, based on principles first put forward by the 19th-century English mathematician Charles Babbage.

At about this time Wallace J. Eckert, a mathematician and astronomer, joined the faculty of Columbia and became active in the laboratory. Convinced that the digital calculating equipment could be even more useful to scientists, particularly astronomers, he persuaded Watson to expand the laboratory. By 1937, the expansion was complete with the founding of the Thomas J. Watson Astronomical Computing Bureau. The Columbia laboratories marked IBM's entry into the world of computers, a move that was to blossom into a position of industry leadership.

Some of the first theoretical papers on computing were published at this time by several mathematicians working independently. Emil L. Post, a logician and professor at the City College of New York, wrote "Finite Combinatory Processes—Formulation 1" in the Journal of Symbolic Logic in 1936, the same year that Alan M. Turing, an Englishman studying at Princeton University, published a paper, "On Computable Numbers, With an Application to the Entscheidungsproblem," in the Proceedings of the London Mathematical Society.

While these two papers dealt with theoretical automatic machines, another by Shannon a year later began to explore how to construct electrical circuits to perform calculations. Shannon, who, as noted earlier, went on to become known as the founder of information theory, proposed in his master's thesis at MIT in 1937 that symbolic Boolean algebraic operations be used to simplify the design of electrical switching circuits. As a corollary, he showed that these electric circuits could also perform the Boolean algebraic operations. He then proposed the design of an electric adder to operate in the base two—one of the first binary digital circuits. Concurrently but independently two groups began work on electromechanical digital computers.

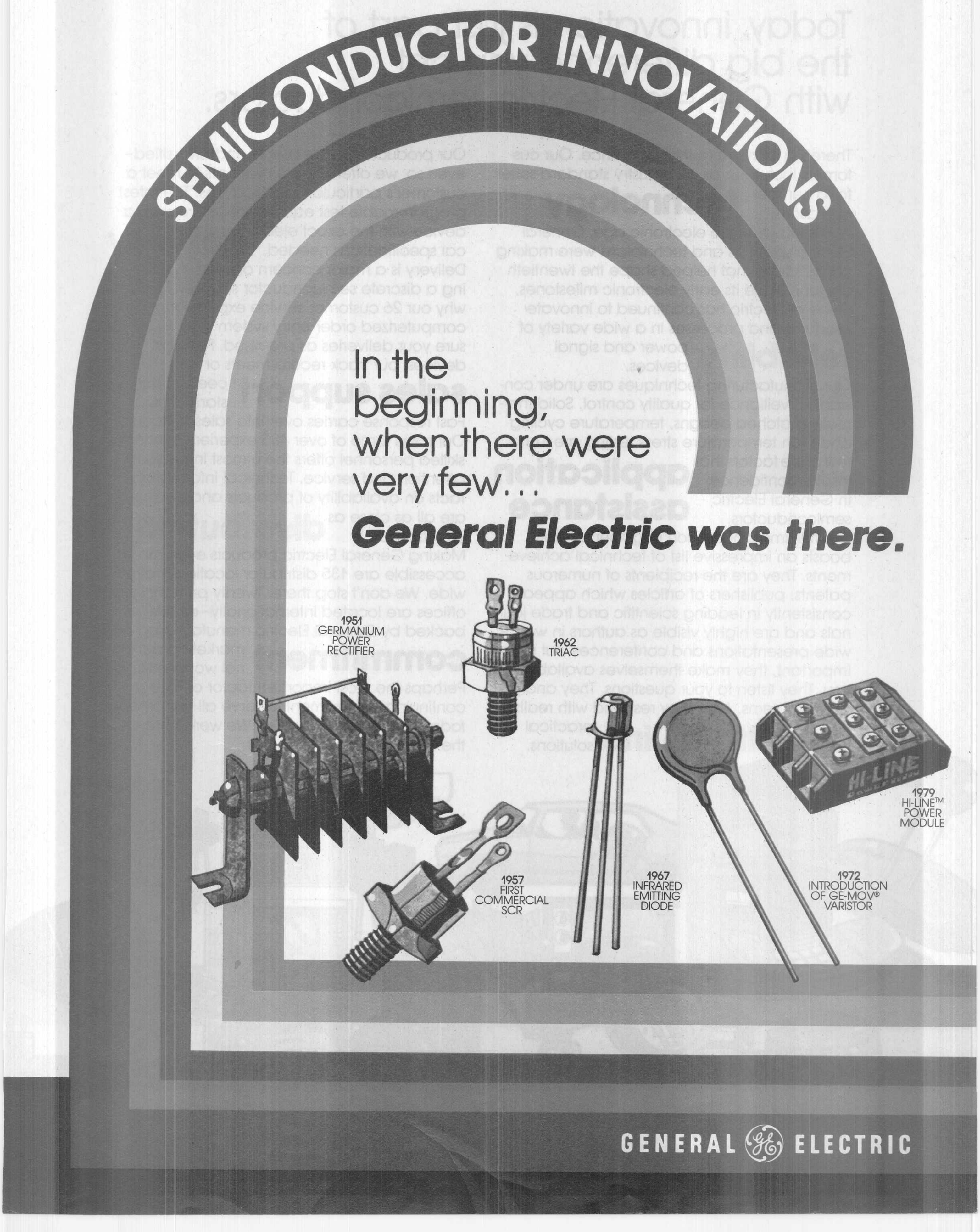
George R. Stibitz, a mathematician at Bell Telephone Laboratories, built his first electrical adding circuits at home in 1937, using scrapped telephone relays. The design of a relay computer shortly became his full-time work at Bell. Assisted by a switching engineer, Samuel B. Williams, Stibitz completed in 1939 the Complex Number Calculator or Relay Interpolator, which later became known as the Bell Laboratories Model 1 relay computer. Although limited to basic addition, subtraction, multiplication, and division, the Model 1 used several concepts for the first time—notably binary-coded decimals. In September 1940, the machine was demonstrated at an American Mathematical Society meeting in Dartmouth College.

Another idea for an electromechanical calculator was formulated by Howard Aiken, a graduate physics student at Harvard University. Through one of his professors, who was also on the board of directors of Columbia University's Astronomical Computing Bureau, the proposal was shown to Wallace Eckert and IBM. IBM was so impressed that it assigned an engineering team led by Clair D. Lake to work with Aiken on the construction of the device. When it was finished and presented to Harvard University in 1944, the Automatic Sequence Controlled Calculator was to be the first automatic general-purpose digital calculator.

In every decade ideas are born and demonstrated and then laid to one side to await maturity and more opportune application. Scores of such productive ideas took root in the 1930s. Two were especially outstanding.

In April 1936, *Electronics* described how engineers at Siemens in Germany had made small condensers by sputtering a thin film of silver on a small piece of mica. They were close to today's thin-film components.

In 1934, J. Dreyer, a researcher at Marconi Laboratories in England, discovered and patented the principle of liquid crystals. Virtually no one was interested. The effect was forgotten until the 1960s.


SEMICONDUCTOR INNOVATIONS
In the beginning, when there were very few...
General Electric was there.
1951 GERMANIUM POWER RECTIFIER
1962 TRIAC
1957 FIRST COMMERCIAL SCR
1967 INFRARED EMITTING DIODE
1972 INTRODUCTION OF GE-MOV® VARISTOR
HI-LINE
1979 HI-LINE™ POWER MODULE
GENERAL ELECTRIC

Today, innovation is just part of the big difference you get with General Electric semiconductors.

There's a lot more to that difference. Our customers look to us as an industry standard-setter for a number of reasons.

technology

At the dawn of the electronic age, General Electric scientists and technicians were making contributions that helped shape the twentieth century. Since its early electronic milestones, General Electric has continued to innovate products and processes in a wide variety of power and signal devices.

reliability

Our manufacturing techniques are under constant surveillance for quality control. Solid thermally matched designs, temperature cycling and high temperature stress testing are just a few of the factors that inspire confidence in General Electric semiconductors.

application assistance

Our full-time application engineering staff boasts an impressive list of technical achievements. They are the recipients of numerous patents, publishers of articles which appear consistently in leading scientific and trade journals and are highly visible as authors in worldwide presentations and conferences. But more important, they make themselves available to you. They listen to your questions. They analyze your problems. And, they respond with realistic, practical solutions.

breadth-of-line

Our product lines are broad and diversified – even so, we often create products to meet a customer's particular specifications. The latest programmable test equipment assures you a device with the exact electrical specifications needed.

delivery

Delivery is a major concern of yours in selecting a discrete semiconductor supplier. That's why our 26 customer service experts and computerized order entry system work to assure your deliveries as promised. For most devices, our track record meets or exceeds industry standards.

sales support

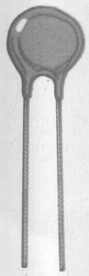
Fast response carries over into sales support. Our sales force of over 485 experienced and skilled personnel offers the utmost in personal attention and service. Technical information, facts on availability of products and pricing are all as close as your phone.

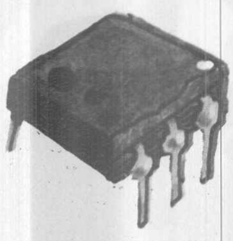
distribution

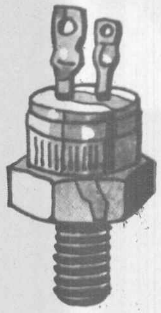
Making General Electric products even more accessible are 135 distributor locations nationwide. We don't stop there. Twenty primary sales offices are located internationally – all are backed by General Electric manufacturing and marketing personnel worldwide.

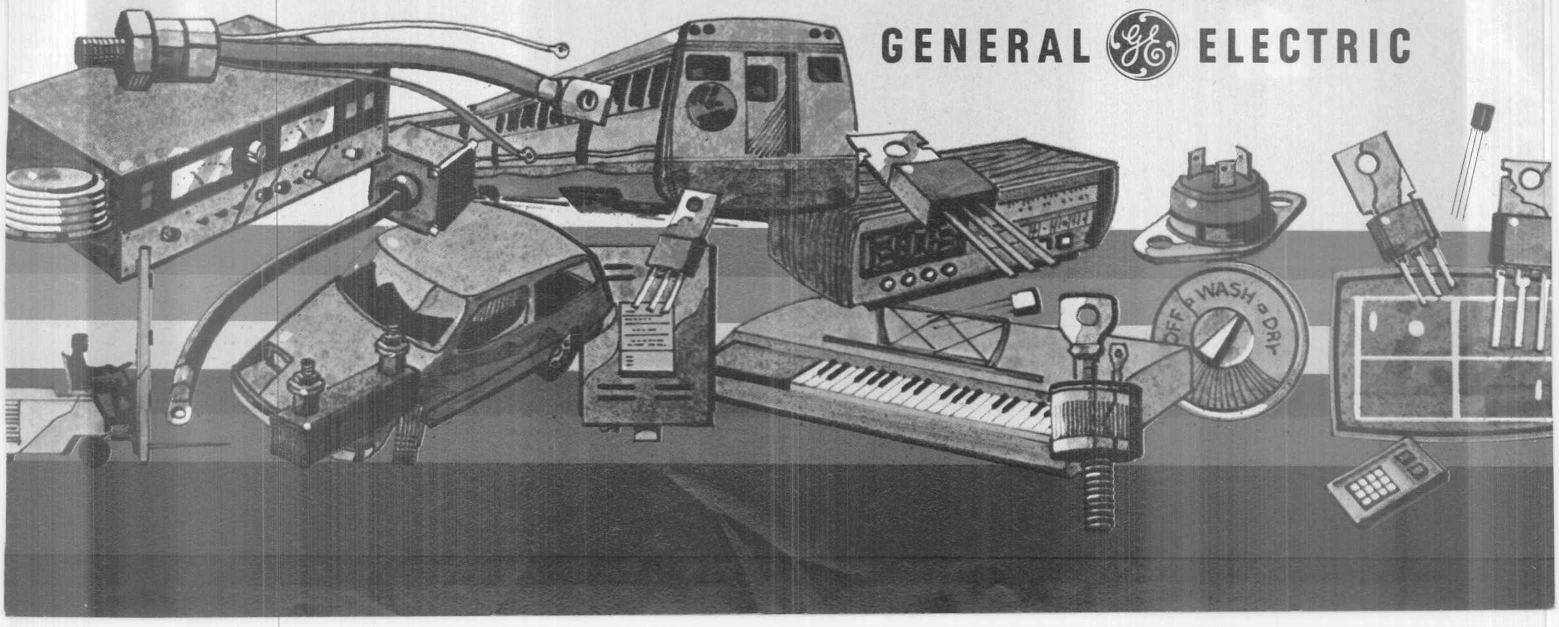
commitment

Perhaps the most important factor of all is our continuing commitment to serve all customers, today, and for the long run. We were here at the start. We are here to stay.





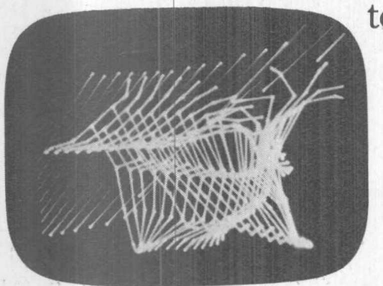



OFF
WASH
DRY

THE COMPUTER COMPANY THAT GIVES BUSINESS THE COMPETITIVE EDGE IS ABOUT TO DO THE SAME FOR U.S. ATHLETES.

No matter how you compete, the difference between a good performance and a great one comes from knowing a little more than the other person. That's the competitive edge.

Now the computers that help people compete in the business and technical fields are out to do the same on the athletic field.



Dr. Gideon Ariel, a former Olympian, has developed a unique athletic training aid using a Data General ECLIPSE® computer system. What Dr. Ariel's device does, is employ our computer to detect the slightest flaw in an athlete's form. First, high speed movies of an athlete's performance are broken down frame-by-frame to show the body in segments, then analyzed for timing, speed and changes in center of gravity. The information is fed into our computer, then played out on a screen allowing the complex motion of, say throwing the javelin, to be seen like no coach has seen it before.

Spotting shortcomings in an athlete's style is a new application for our Data General ECLIPSE computer that has us incredibly excited. In fact this ECLIPSE system will be used by the Sports Medicine Committee at the Olympic Training Camp in Colorado Springs.

The Computer of the U.S. Olympic Sports Medicine Committee

From the small CS/20 Commercial System to the large, multi-user business ECLIPSE M600, Data General computers are doing new things every day to enhance people's performance and give them a more competitive edge. For a reprint of an article on Dr. Ariel and his work, plus a brochure on our Data General business ECLIPSE computer, mail the coupon.

☐ I want to compete better, too. Please send me the article on Dr. Ariel and your business ECLIPSE brochure.

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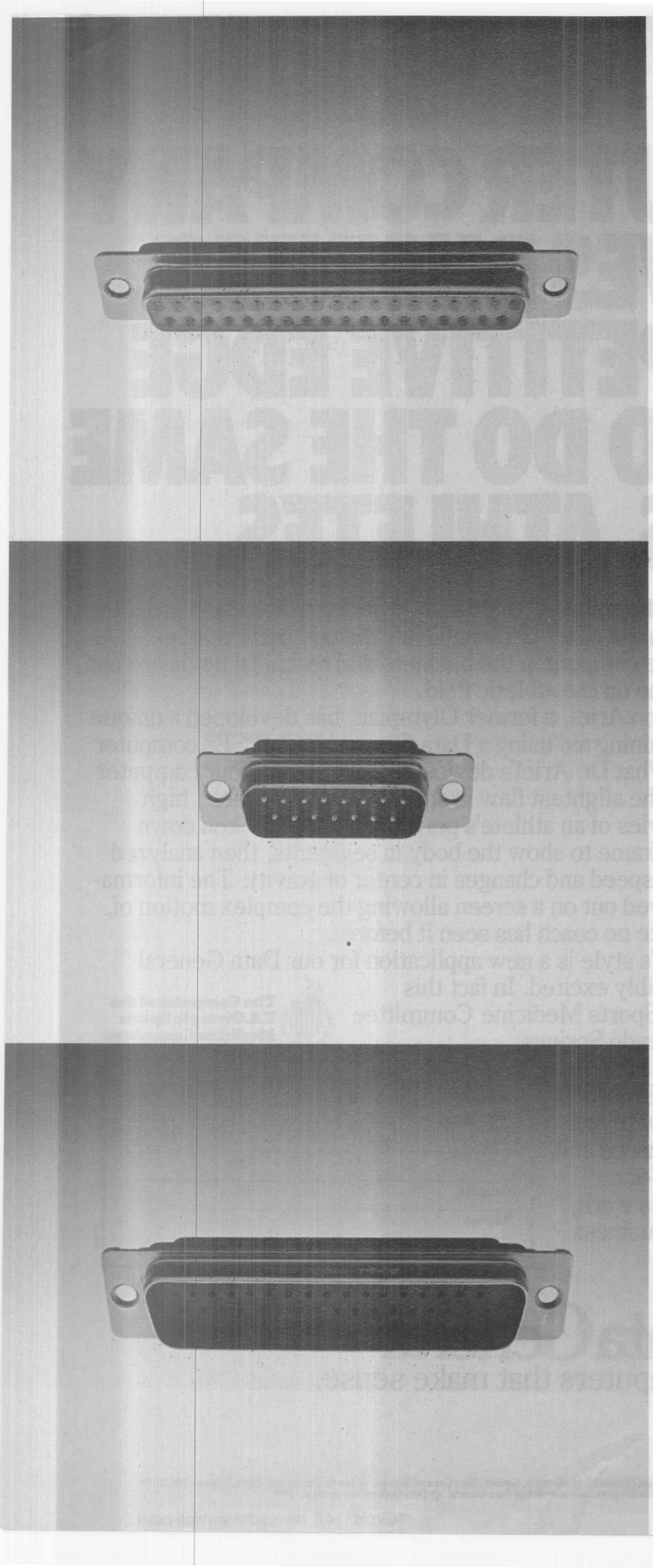
E417

Data General

We make computers that make sense.

Data General Corporation, Westboro, MA 01581, (617) 366-8911. Data General (Canada) Ltd., Ontario, Canada. Data General Europe, 61 rue de Courcelles, Paris, France, 766.51.78. Data General Australia, (03) 89-0633.

Circle 147 on reader service card

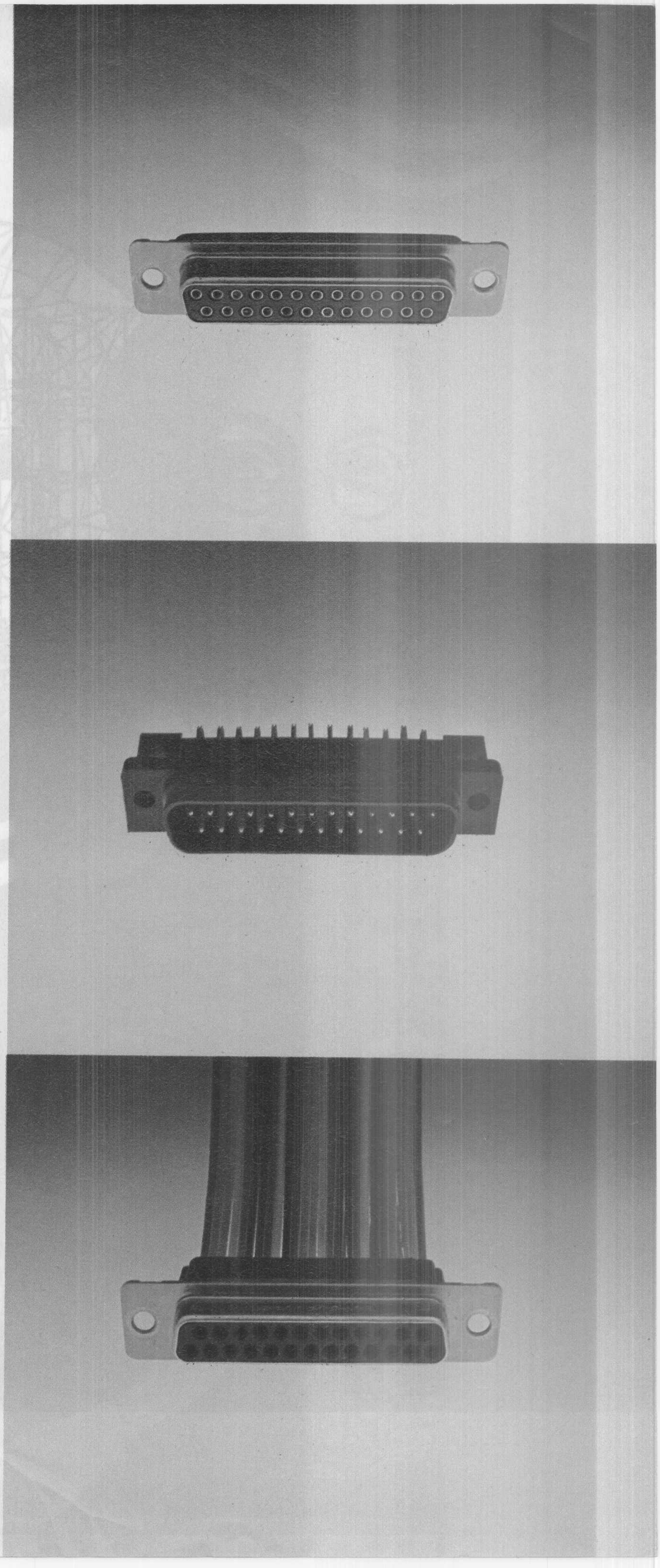


THE OLD STANDBY THAT WON'T STAND STILL.

In the beginning, there was the Cannon® Original D connector with solder pot contacts in a two-piece insulator. But as technology leapt forward, so did we. With our BURGUN-D, ROYAL-D and long line of designs that answered new needs and became industry standards.

Now our latest technology can be seen in our Mas/Ter™ D pin-and-socket connectors designed for mass-terminating flat cable or individual wires. Our Mas/Ter D contact design provides 25% more wire-to-contact surface area to give you increased reliability and conductivity. And for added flexibility, they are intermateable and intermountable with our entire D Subminiature line.

If you're not content to let technology pass by, look into the Cannon D Subminiature and Mas/Ter D connector evolution. You'll find a huge selection of low-cost connectors and accessories available right now through our worldwide distributor network. For immediate information refer to our pages in EEM. For literature, the name of your local Cannon distributor or other information contact Rectangular Division Marketing Manager, ITT Cannon Electric, a Division of International Telephone and Telegraph Corporation, 666 E. Dyer Road, Santa Ana, California 92702. Telephone: (714) 557-4700. TWX: 910-595-1131. TELEX: 65-5358.



CANNON ITT

You can always connect with Cannon.

Circle 149 on reader service card

AT WAR

HUMANITY'S GREATEST ACHIEVEMENTS ARE OFTEN INSPIRED BY CRISIS AND PERIL. THUS, THE EXIGENCIES OF WORLD WAR II TRANSFORMED ELECTRONIC TECHNOLOGY FROM MERE ENTERTAINMENT AND NOVELTY INTO THE MEANS TO SURVIVAL—AND FOR THE ALLIES, ULTIMATE VICTORY. OUT OF THE CONFLAGRATION WERE BORN COMPUTERS, MINIATURIZATION, RADAR, LORAN, AND GUIDED MISSILES. THEN, TURNING FROM WAR TO LIFE-ENRICHING PURSUITS, THE TECHNOLOGY BROUGHT FORTH COMMERCIAL TELEVISION BROADCASTING AND STEREO AND TAPE RECORDING. ELECTRONICS WAS BEGINNING TO ASSUME ITS MODERN ALL PERVADING CHARACTER.

Chapter 4

Totalitarianism was on the march. Another World War was in the making.

Back in 1936, Germany had formed the Rome-Berlin Axis with Italy and signed the Anti-Comintern Pact with Japan. By spring of 1939, Austria and Czechoslovakia had fallen to Hitler's armies without a struggle, but with the German invasion of Poland on Sept. 1, Britain and France declared war on the Axis powers. Then for months, while German and Russian forces tore Poland asunder and the Soviet Army invaded Finland, nothing happened on the Western Front. That quietude was shattered on April 9, 1940. With roaring artillery and screaming bombs Hitler's war machine began its sweep down Europe's Northwestern coast into France, hurling the British Army into the sea at Dunkirk.

Winston S. Churchill, who took office as Britain's Prime Minister in May 1940, wrote later:

"Within six weeks we were to find ourselves alone, almost disarmed, with triumphant Germany and Italy at our throats, with the whole of Europe in Hitler's power, and Japan glowering on the other side of the globe."

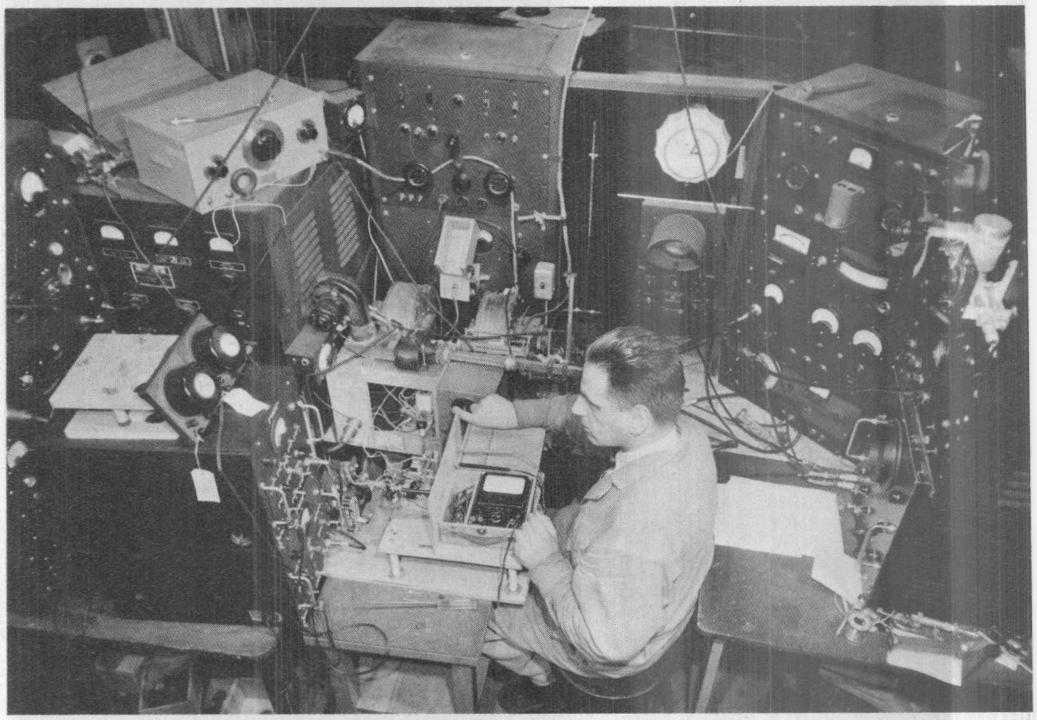
The British government, having paid out more than $4.5 billion for arms, also faced penury. In November 1940 Churchill wrote to President Franklin D. Roosevelt for help, and a month later Roosevelt responded. He publicly proposed Lend-Lease—American arms for Britain, with payment deferred—and when it became law in March 1941, the U. S. became, in Roosevelt's words, "the great arsenal of democracy." Over the next four years it sent more than $50 billion worth of war materials to the Allies. Roughly half went to Britain.

Before 1941 was out, the Japanese attack on Pearl Harbor had drawn the U. S. into the war. And before World War II ended, 49 nations at one time or other were fighting on the side of the Allies against 7 Axis powers. The Soviet Union, after swallowing Estonia, Latvia, and Lithuania, had joined the Allies by default when a 3-million-man German force swarmed onto Russian soil in June 1941.

The war transformed the U. S., lifting it from the doldrums of the Great Depression into an era of feverish production. There was a great mobilization of industrial workers as well as soldiers. Some 3.6 million women joined 6 million men on the nation's industrial front to produce ships, trucks, guns, planes and other war supplies, and some 16 million men and women were in uniform by VJ-Day.

There was also a great effort in civil defense. Air raid wardens policed brownouts and blackouts, especially in seaboard cities, where the glow of lights could silhouette Allied shipping for enemy submarines. Something like 1.5 million civilian spotters scanned the seas for U-boats and the skies for enemy aircraft.

As part of the home front effort, civilians bought close



Starting from scratch. Technology skills had to be mobilized on a national scale to counter the Nazi threat, and new research laboratories were established. One of these was the Radiation Laboratory at MIT (above), which became the center of radar research.

Mobilization. America responded to total war by bringing to bear its industrial might in expanded production facilities. The use of women in factories became commonplace, as typified in this Western Electric radar assembly line in Kearny, N. J.

to $50 billion in war bonds. With imports restricted, some commodities became scarce. Synthetic rubber came into use, and scrap metal and material of all kinds was collected—everything from empty toothpaste tubes to bacon grease for use in explosives.

Americans endured rationing of staples like meat, butter, coffee, sugar, and gasoline, paying for the items with special stamps as well as cash. They grew fresh vegetables in so-called Victory gardens in back yards, empty lots and parks. Black markets also flourished. Wage and price controls, administered by a Federal Office of Price Administration, kept inflation in check.

Then, just as victory in Europe was in sight, a stunned nation learned on April 12, 1945 of the death of President Roosevelt. On May 7, Germany surrendered unconditionally to the Allies.

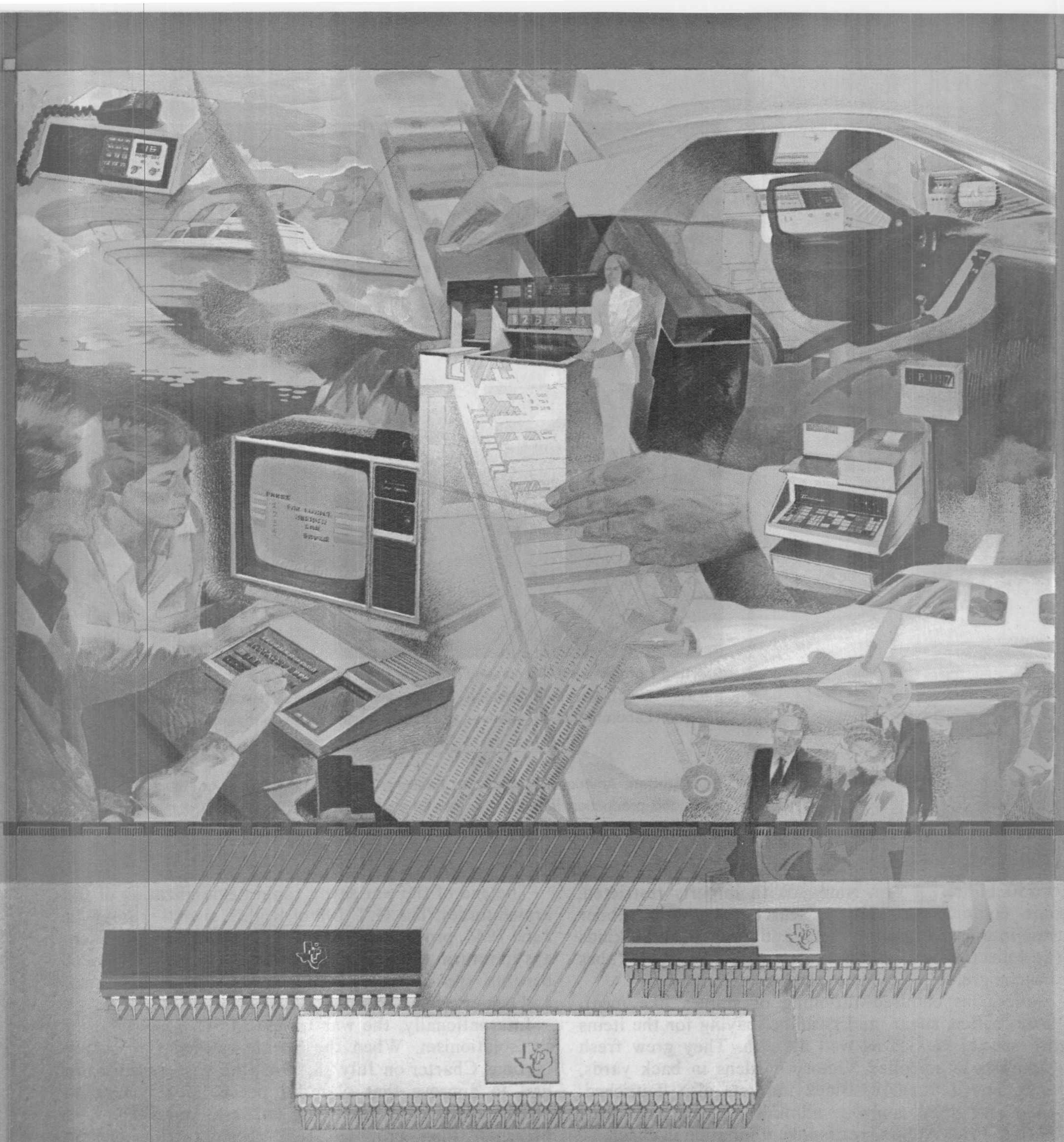
On July 16, at dawn on a desert near Alamogordo, N. M., the atomic age was born. Scientists watched in awe from miles away as the world's first atomic device exploded and mushroomed upward from its fixed position atop a pole. Production of two aerial bombs was rushed, and on Aug. 6, 1945, an American B-29 crew dropped the first on Hiroshima. Three days later the second fell on Nagasaki. The next day the Japanese government asked the Allies about terms of surrender. The formal signing of unconditional surrender took place on the battleship Missouri in Tokyo Bay on Sept. 2, 1945.

The end of the war saw a rapid demobilization of the armed forces. The G. I. Bill of Rights, signed into law in June 1944, provided funds that allowed millions of veterans to return to school. It also gave them unemployment benefits, special hospitals, and loans for homes, farms, and businesses.

Internationally, the war turned the U. S. away from its isolationism. When the Senate ratified the United Nations Charter on July 28, 1945, the U. S. became the first to approve that plan for peace. It also became deeply involved in rebuilding its destroyed allies. The Marshall Plan proposed that reconstruction of the world's postwar economy be financed largely by the U. S. The Congress approved it, and President Harry S. Truman signed it into law on April 3, 1948. The nation was in a mood to forgive and forget. The fighting was over, but the cold war was just beginning.

While nation had battled nation to the death, the electronics industry entered upon a period of extraordinary creativity and growth. Under the stimulus of a multibillion-dollar flow of funds, it changed from a timid, consumer-oriented radio industry into a heroic producer of rugged, reliable military equipment, capable of withstanding the battlefield extremes of temperature, humidity, vibration, and shock.

Radar matured from infancy almost overnight and,



Choose TI's 16-bit 9900 Family. For price. For performance. And because it's production-proven. You'll be in the best of companies.

By the hundreds, companies are staking new product designs on TI's 9900 Family. A wide diversity of products. By companies large and established. By those small and growing. The brief recap on the opposite page lists just a few of the many innovators who have seen the future and chosen the 9900 Family. For a lot of good reasons:

Here-and-now compatible family

Unlike others who plan or promise, the 9900 Family is a fact. Available

from your TI distributor today. Microprocessors. Peripherals. Microcomputer modules. Development tools. All compatible to protect your software investment as you move from one product design to another.

From the beginning, TI has been the 16-bit leader. The 9900 Family has grown. Matured. Become second sourced.

We'd like to say it's complete. But that will never be. TI is firmly committed to the Family's expansion according to your needs and as new technologies develop.

Price/performance microprocessor choices

Utilizing the most advanced architecture on the market today, the microprocessors in the Family include the original NMOS TMS9900. The functional I^2L equivalent, the SBP9900A, for harsh environments. The lower-cost TMS9980/9981 versions for smaller systems.

Now coming into production: TMS9940, the industry's first 16-bit single-chip microcomputer with on-chip memory and I/O.

In total, an unequalled choice that lets you more easily and quickly match price and performance to your designs.

Low-priced peripherals

At last count, 14 peripherals support these microprocessors. The LSI "nuts and bolts" needed to complete your system. Easily. Economically.

For memory expansion to 16 megabytes there's the new TIM99610 Memory Mapper.

To fill your communication needs: TMS9902 Asynchronous Controller, TMS9903 Synchronous Controller, TMS9911 DMA Controller, and the new TMS9914 GPIB Adapter.

Also of interest: The TMS9927 CRT Controller and the new color graphics TMS9918 Video Display Processor.

Cost-conscious microcomputer modules and minicomputers

For a headstart in systems design, look into the Family's series of 16-bit TM990 microcomputer modules for evaluation, systems prototyping, and OEM applications.

The TM990 series includes standalone CPUs, memory expansion, and I/O expansion modules. And modules for program development. For learning and teaching.

TI's compatible 990 minicomputers extend the 9900 Family's level of integration to packaged host systems for distributed processing and a wide variety of other applications.

End products:
Where the 9900 Family is shining.

Every day, the 9900 Family is proving itself where it counts. In the marketplace. At the core of new products, new designs.

Many major companies, whose large resources and staffs allow them to weigh carefully all considerations and options, have elected to build products around the 9900 Family. Among them are Litton Aero Products, Allen-Bradley, Tektronix, Veeder-Root, Sweda International, John Fluke, Amoco, Fisher Controls, E.I. DuPont, Sun Electric, General Electric, Otis Elevator.

Also, a large number of young, aggressive companies have selected the 9900 Family . . . companies who cannot afford failure. Among them are Acuity Systems, Optronics Ltd., Harowe Systems, Micor, Cubic, Praxis Ltd., Nicolet, Delta Data.

Texas Instruments, where the bottom line is as important as anywhere else, uses the 9900 Family as the heart of its pacesetting home computer. In its Loran-C receiver. In minicomputers and terminals. In satellite navigation systems. In aircraft tracking and collision avoidance support systems.

The proof is convincing. For performance, economy, versatility, support, your first choice in 16-bits is the 9900 Family. You'll be in the best of companies.

Here-and-now Pascal

Just as many are playing catch up in 16-bit microprocessors, they're working overtime on high-level languages. Particularly Pascal. But TI has had operative Pascal for several years. Long enough to refine it for microprocessor applications.

TI's new Microprocessor Pascal offers the most extensive support available: Editor, compiler, host debugger, configurator, native-code generator, and run-time support.

Also: Compilers for Fortran and interpreters for Power Basic — all available on TI's floppy-based AMPL development system.

Versatile development systems

In addition to a broad family of hardware, you need reliable, available — and economical — development systems. These the 9900 Family has. To boost programmer efficiency while cutting costs.

The AMPL* prototyping lab is a complete set of software and hardware development tools for the entire 9900 Family. It provides real-time emulation and logic-state trace. It can be programmed for complex test and debugging sequences.

With this one versatile unit, you can not only develop software but also check out and verify software and hardware as you go.

Compared on a feature-by-feature, dollar-by-dollar basis, the AMPL lab is the best 16-bit microprocessor development system for your money.

Help is available

Whenever you have a tough question or need another opinion, talk with your nearest TI systems engineer or TI distributor applications engineer. If you want to learn more about the 9900 microprocessors, TM990 modules, Microprocessor Pascal and the AMPL lab, TI training courses are being held weekly. Call your TI field sales office or your authorized TI distributor for details and locations.

For a copy of the new brochure on the 9900 Family, contact your TI distributor. Or write Texas Instruments Incorporated, P.O. Box 1443, M/S 6404, Houston, Texas 77001.

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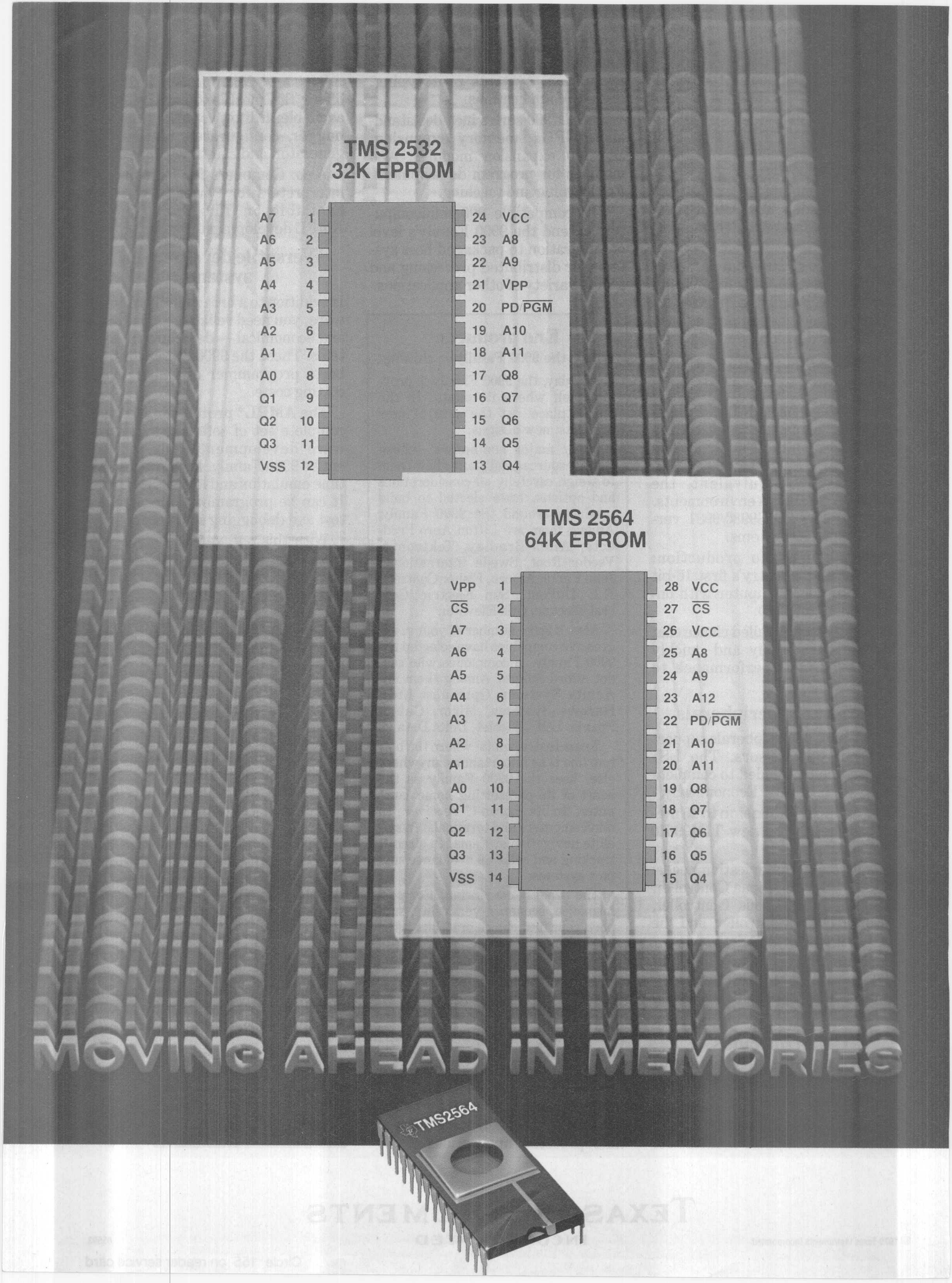
TEXAS INSTRUMENTS
MOVING AHEAD
IN MICROPROCESSORS

TEXAS INSTRUMENTS
INCORPORATED

85593



TMS 2532
32K EPROM
A7 1 | 24 VCC
A6 2 | 23 A8
A5 3 | 22 A9
A4 4 | 21 VPP
A3 5 | 20 PD/$\overline{PGM}$
A2 6 | 19 A10
A1 7 | 18 A11
A0 8 | 17 Q8
Q1 9 | 16 Q7
Q2 10 | 15 Q6
Q3 11 | 14 Q5
VSS 12 | 13 Q4
TMS 2564
64K EPROM
VPP 1 | 28 VCC
$\overline{CS}$ 2 | 27 $\overline{CS}$
A7 3 | 26 VCC
A6 4 | 25 A8
A5 5 | 24 A9
A4 6 | 23 A12
A3 7 | 22 PD/$\overline{PGM}$
A2 8 | 21 A10
A1 9 | 20 A11
A0 10 | 19 Q8
Q1 11 | 18 Q7
Q2 12 | 17 Q6
Q3 13 | 16 Q5
VSS 14 | 15 Q4
MOVING AHEAD IN MEMORIES
TMS2564

The first 64K EPROM. From Texas Instruments. Naturally.

Introducing the TMS2564. The industry's first 64K EPROM. The densest yet. With all the high-performance features of TI's 5-V EPROM family. Features like 8-bit word configuration, fully static operation, automatic chip-select/power down, and low-power.

Pin compatibility

TMS2564 is offered in a 600-mil, 28-pin dual-in-line package. But, it's compatible with industry standard 24-pin 64K ROMs, as well as less dense EPROMS.

This is because pins 3 through 26 of the TMS2564 are compatible with pins 1 through 24 of the 24-pin devices. Compatibility is enhanced by reserving both pins 26 and 28 for the 5-V supply. So, with a supply trace to pin 26, both 24 and 28-pin devices can be used, with no jumpering.

Fully static

Like all TI EPROMS, the TMS2564 maintains the fully static tradition that makes designing easier.

No timing signals. No clocks. No strobes. No refresh. No problems. Simply, cycle time equals access time.

Lowest power ever

Operating at an access time of 450 ns with a power dissipation of only 840 mW maximum or less than 13 μW per bit, it's the lowest power per bit ever achieved in EPROMS.

TI'S GROWING EPROM FAMILY

Device	Description	Power Supply	Max Power (0°C) Operating	Max Power (0°C) Standby	Access Time
TMS2564	64K	5 V	840 mW	131 mW	450 ns
TMS25L32	32K	5 V	500 mW	131 mW	450 ns
TMS2532	32K	5 V	840 mW	131 mW	450 ns
TMS2516-35	16K	5 V	525 mW	131 mW	350 ns
TMS2516	16K	5 V	525 mW	131 mW	450 ns
TMS2508-25	8K	5 V	446 mW	131 mW	250 ns
TMS2508-30	8K	5 V	446 mW	131 mW	300 ns
TMS2716	16K	+ 12, ± 5 V	720 mW	—	450 ns
TMS27L08	8K	+ 12, ± 5 V	580 mW	—	450 ns
TMS2708	8K	+ 12, ± 5 V	800 mW*	—	450 ns
TMS2708-35	8K	+ 12, ± 5 V	800 mW*	—	350 ns

*$T_A = 70°C$

Easy programming

The TMS2564 is designed to facilitate rapid program changes in high density, fixed memory applications.

All that's needed for simple, in-system programming, is a single TTL level pulse.

You can program in any order. Individually. In blocks. At random. So, programming time is reduced to a minimum. And, you can use existing 5-V PROM programmers.

Erasing? Simple ultraviolet. Just like any other EPROM.

Widest choice

By adding the new TMS2564 to our fast-growing EPROM family, we offer the designer a product breadth unmatched by any other supplier.

All TI EPROMS are available in 600-mil packages with JEDEC compatible pin-outs.

And they all share the reliable N-channel process technology.

TI's growing EPROM family. For all your present and future memory requirements.

For more information about the first 64K EPROM, or any other family member, call your nearest field sales office or authorized distributor. Or write to Texas Instruments, P.O. Box 1443, M/S 6955, Houston, Texas 77001.

Fifty Years of Innovation

TEXAS INSTRUMENTS
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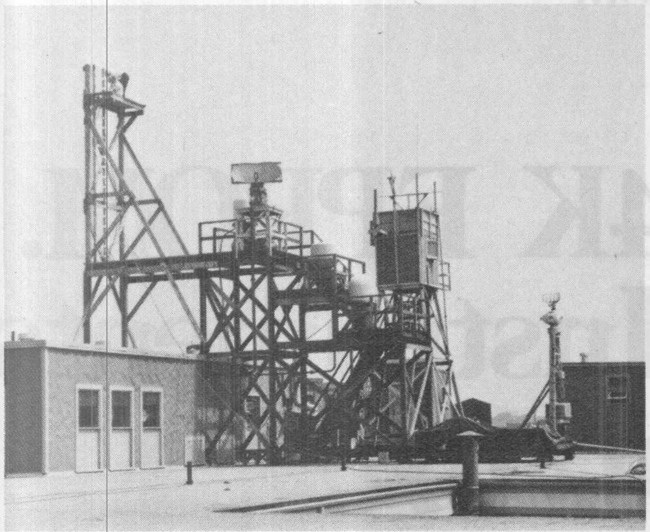
85126 A

Circle 157 on reader service card



Rooftop radar. The MIT Radiation Laboratory was the scene of much of the experimental work that produced U. S. military radar. Shown here are experimental antennas atop the laboratory's Building 6 near Massachusetts Avenue in Cambridge.

British pioneer. Sir Robert A. Watson-Watt is credited with taking radar out of laboratory and making it practical. His work helped Britain achieve the system that proved itself in the Battle of Britain. Later, Watson-Watt visited the U. S. to aid American radar efforts.

for openers, helped the Royal Air Force win the crucial Battle of Britain. Sonar was improved, and Allied navies used it to pinpoint the position of submerged German U-boats. Miniaturization crammed circuitry into tiny spaces for airborne and backpack applications. It also gave birth to the proximity fuze, which gave Allied antiaircraft, mortar and artillery batteries an edge in hitting targets. Giant calculators, forerunners of the modern computer, were perfected and saved countless hours in figuring ballistic trajectories and the astronomical tables used in navigation. The walkie-talkie, developed back in 1933 for the Army Signal Corps, improved infantry communications.

On the home front, electronic instruments advanced to the point where they could automatically test assembly-line components and help relieve a civilian manpower shortage. In the aircraft, munitions, and metal-working industries, around-the-clock schedules put industrial electronics to the test in controllers for resistance welders and other machinery. It passed with flying colors, thanks to the ruggedized tubes developed in the 1930s.

World War II was the first war in which electronics played a decisive role, and the effect on the industry was phenomenal. A history of the War Production Board notes:

"The electronics industry expanded during the war to more than 12 times its monthly prewar net factory filling value on end equipments and from over 2 to 20 or 30 times on the major components. The expansion of labor employment was from a prewar peak of approximately 110,000 workers to a war peak of 560,000."

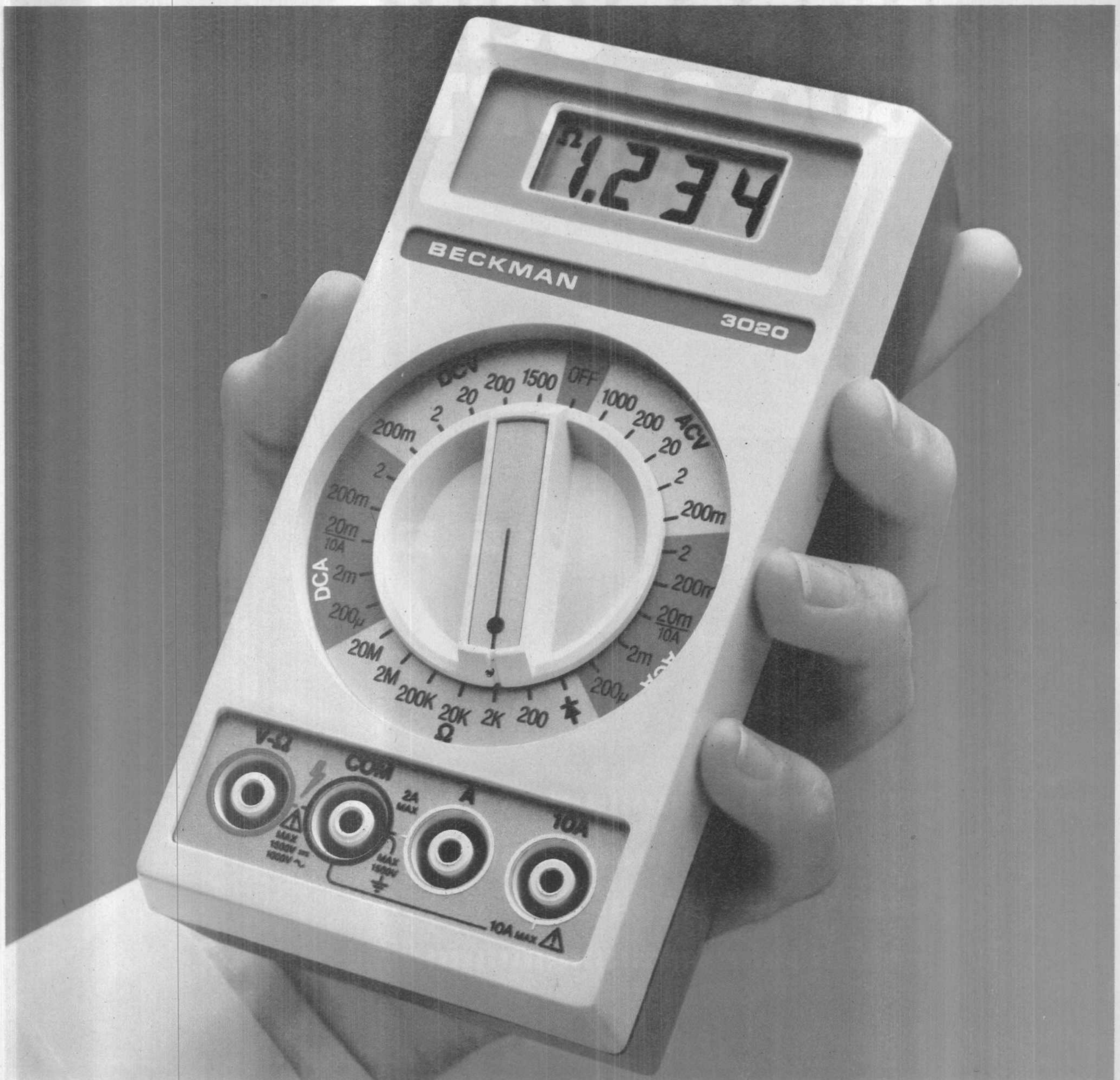
The radio industry was never to return to its relatively small position in manufacturing, dependent on the rise and fall of a single consumer product. Civilian production of radios was at a minimum during the war, but airmen, seamen, tank crews, and foot soldiers relied on radio sets as lifelines of communication. In 1941, the War Production Board reported, for example, that 55 radio set manufacturers had factory sales of $240 million. By 1944, what was being referred to as the radio and radar industry, including parts makers, reached annual sales of $4.5 billion—an increase of 1,875%.

Each tank of its day contained some $5,000 worth of radio equipment, and a heavy bomber contained $50,000 worth "of the most complex and delicate radio devices," according to William L. Batt, chairman of the War Production Board's Requirements Committee.

There were other revealing War Production Board statistics. Total vacuum tube production from 1942 through the first half of 1945 was valued at more than $1 billion, or about 15% of the value of electronic end-user equipment. Capacitor manufacturers, who had sold about $5 million worth a month before Pearl Harbor, were selling $12 million a month by VJ-Day. Similarly, the 42 manufacturers of radio and radar transformers, whose output alone was valued at $11 million in 1939, had grown to at least 95 by late 1944 and the monthly output was about $14 million by 1945.

Standardization of all this radio and radar equipment was of course crucial to military efficiency, and much of it was handled by the engineering department of the Radio Manufacturers Association. Early in 1942 there were 2,300 designs of radio tubes in Army and Navy equipment. By the end of the war, military tube types had been reduced to 224, with a single specification for each type. Standards were also developed for many other components, including electrical indicating instruments, capacitors, coaxial cables, insulators, toggle switches, resistors, and rheostats.

Even before the attack on Pearl Harbor, some electronics leaders had seen the need for a major industrial effort. In an address to the summer convention



Beckman's digital multimeter is ready to handle any job you are.

Continuity checks. High current measurements. In-circuit resistance measurements and semiconductor tests. Whatever the job, if a multimeter is called for, call for a Beckman digital multimeter.

It features Insta-Ohms™ quick continuity indicator (exclusive to Beckman), 10-amp current range, in-circuit measurement capability in all six ohm ranges, a dedicated diode test function, and up to two years normal operation from a common 9V battery.

The Model 3020 has seven functions, 29 ranges, and 0.1% Vdc accuracy.

And it uses band-gap reference elements, thin-film resistor networks, gold switch contacts and custom designed CMOS LSI chips to assure long-term accuracy and reliability.

So, for ease of operation and reliability from your digital multimeter, choose Beckman.

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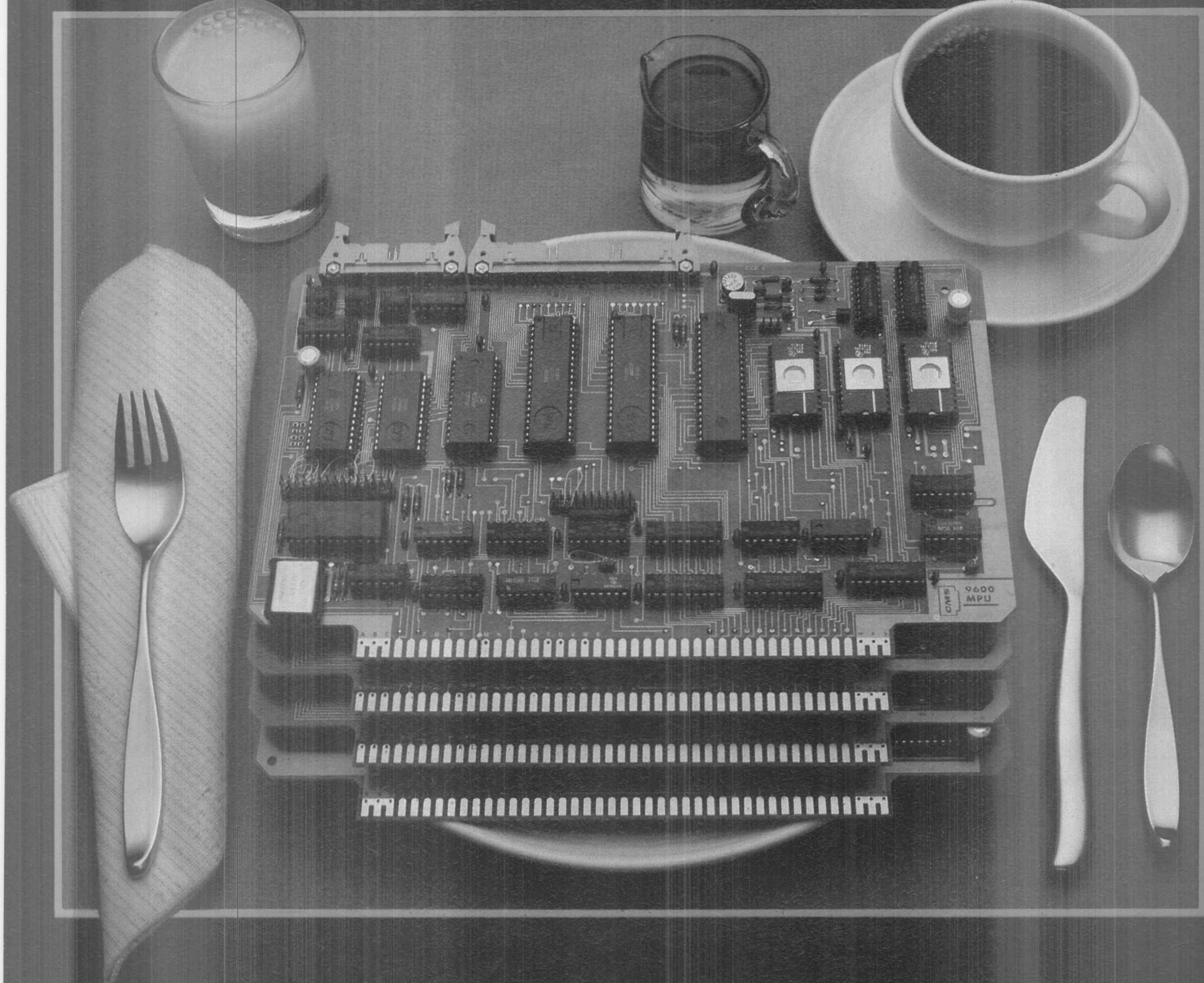

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Microwave key. MIT's Radiation Laboratory revolutionized radar by using microwaves. Inspecting an early American version of the cavity magnetron are E. G. Bowen, a British scientist (left), and laboratory directors L. A. DuBridge (center) and I. I. Rabi.

In training. In 1941, the use of radio-location, or radar, techniques for tracking enemy aircraft and directing anti-aircraft fire was still relatively primitive. Here British operators are shown being trained in electronics with crude equipment.

banquet of the Institute of Radio Engineers on June 24, 1941, Frederick Emmons Terman of Stanford University, the group's president, said:

"Today the armed services of the nation are drawing mightily upon the intellectual inheritance handed down by radio pioneers . . . Radio and its allied arts will have much to do with the placing of force where force is needed in the event this country goes to war. Some of these applications will be to the handling of communications . . . But in addition electronic technicians are finding totally new employments . . . in navigation and in searching out the enemy, whether he come by sea, land or air. . . . The most intricate military control equipment, much of it based upon radio devices, will be commonplace in our services when and if war comes to us."

Earlier, in July 1940, the board of directors of the American Institute of Electrical Engineers had passed a resolution to the effect that the organization would help President Roosevelt carry out a program for the defense of the country. In September, the AIEE publication, Electrical Engineering, carried an article on the same theme by L. A. Hawkins, executive engineer in the research laboratory of the General Electric Co. in Schenectady, N. Y. Hawkins wrote:

"The Nazi juggernaut was created by engineering, and it is only by engineering that it can be destroyed. . . . The fascinating search for truth for its own sake must be temporarily abandoned and thought and effort concentrated on the problems of military preparedness. . . Research and engineering must work together as never before to the attainment of a single end."

Others were thinking along similar lines. Vannevar Bush, president of the Carnegie Institution of Washington and an electrical engineer, had already approached President Roosevelt and his advisers and impressed upon them the need to mobilize science for war, specifically by familiarizing researchers with the needs of the military and the military with the possibilities of science.

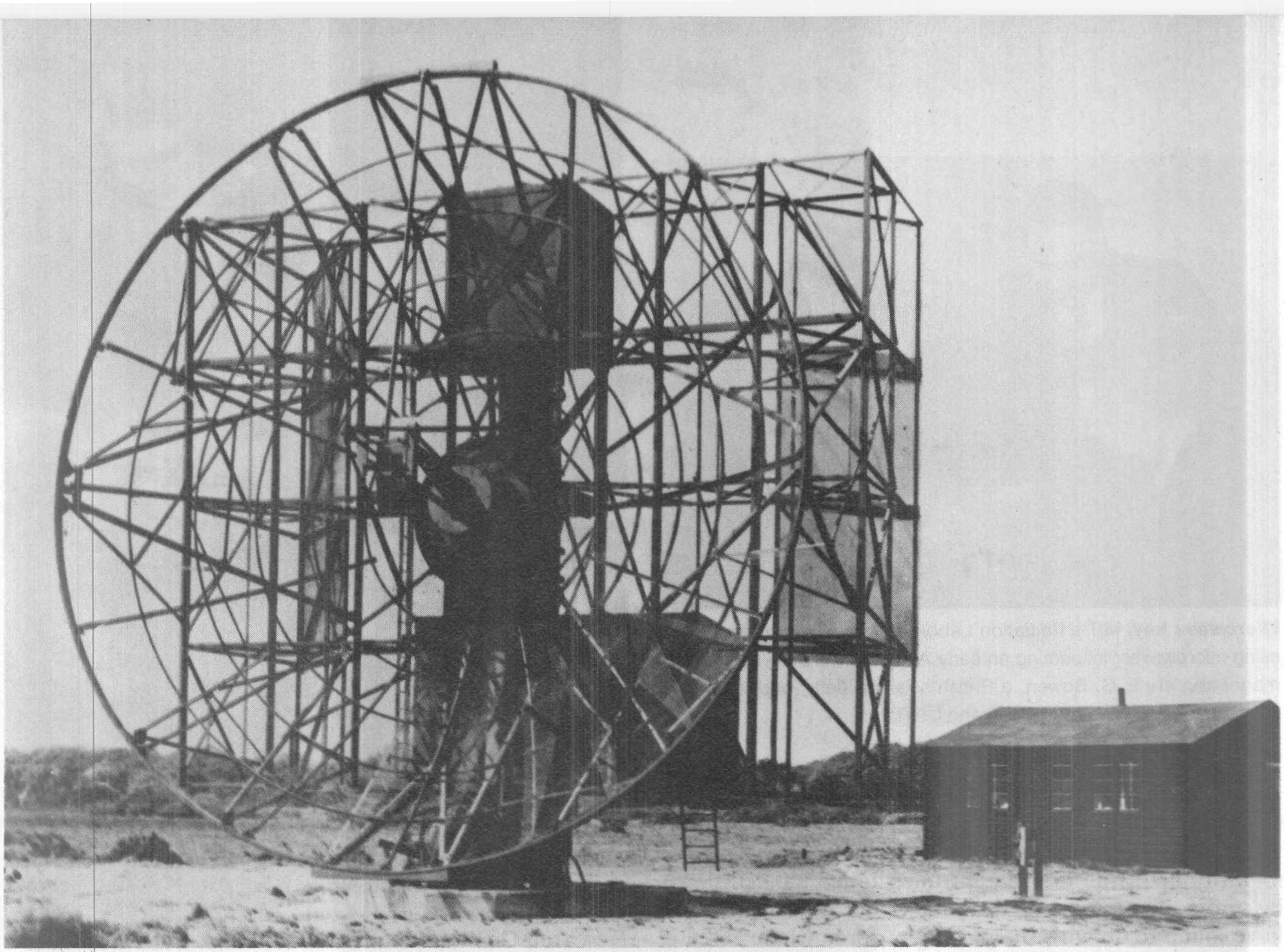
When the Government created the National Defense Research Committee on June 27, 1940, Bush was named its chairman. Other members included Karl Taylor Compton, a physicist and president of the Massachusetts Institute of Technology; James Bryant Conant, a chemist and president of Harvard University; Frank Baldwin Jewett, an electrical engineer and president of both the National Academy of Sciences and Bell Telephone Laboratories; and Richard Chace Tolman, a physicist and professor of physical chemistry and mathematical physics at the California Institute of Technology. The U. S. Commissioner of Patents and one representative each from the Army and the Navy also joined the panel.

The committee's job was "to correlate and support scientific research on the mechanism and devices of warfare, except those relating to problems of flight." (The latter fell within the purview of the National Advisory Committee for Aeronautics and Space Administration.)

One of the committee's first orders of business, therefore, was to bring its existence to the attention of education research centers around the country and to compile an inventory of the nation's resources, both scientific personnel and physical facilities. Conant wrote to 50 leading research centers. The objective was to match people and projects with as little disruption of education programs as possible.

In addition, some new research laboratories had to be set up. For example, with growing German submarine attacks on shipping, a big program was needed in antisubmarine warfare but no center for such activity existed. Two were quickly established by the National Defense Research Committee—one under contract with Columbia University at New London, Conn., and the other with the University of California at San Diego.

Similarly, a new center for radar research had to be



Fighter director. This is one of the first pictures ever released of a British radar installation. Called a type 16 Station, it was used mainly in offensive operations for observing and passing range and height data to group headquarters, permitting tactical fighter control.

Mickey Mouse. Its twin antennas inspired the nickname of the U. S. Army's SCR-547 anti-aircraft radar shown at the front in Italy in 1945. It was designed to measure the height of enemy planes, the data being transmitted to a remotely located gun installation.

Three-dimensional. A five-man crew was required to operate the 9936 U. S. Signal Corps radar shown here on an Italian hillside. Three seated operators traced, respectively, the degrees from the north, the elevation, and the range of the target.

established just about from scratch. Although some work in long-wave radar had been done in the country, the field of microwave radar was unexplored. The Massachusetts Institute of Technology in Cambridge Mass., was chosen for the radar center, and this new Radiation Laboratory grew to be the largest single undertaking of the committee.

Countermeasures work—the jamming of enemy communications and radar—also required new laboratories. The largest of these, the Radio Research Laboratory at Harvard University, was headed by Terman of Stanford.

The National Defense Research Committee operated throughout the war, finally disbanding in January 1947. Initially it had reported to the National Defense Council. Then in June 1941, to facilitate the translation of

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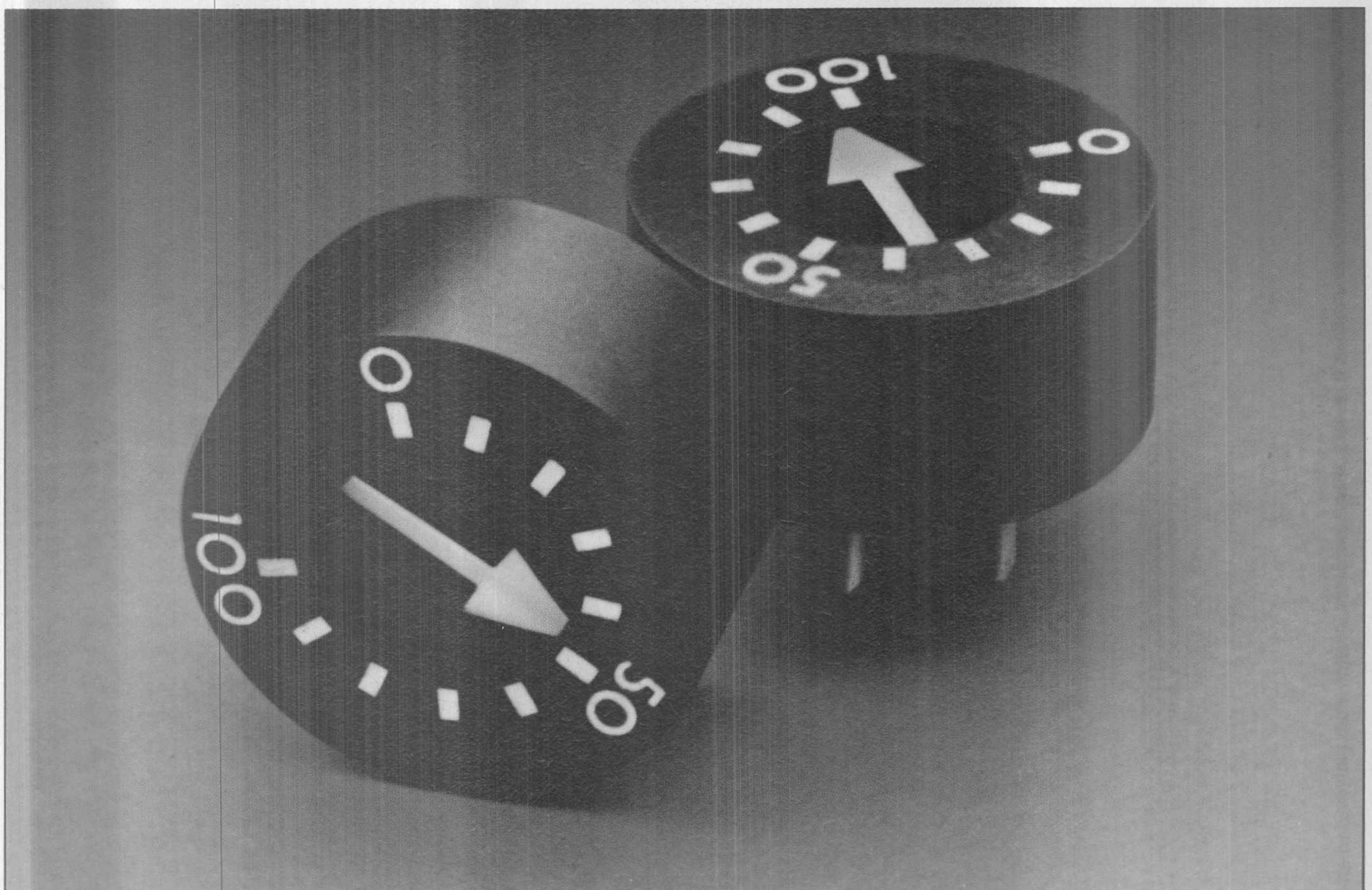

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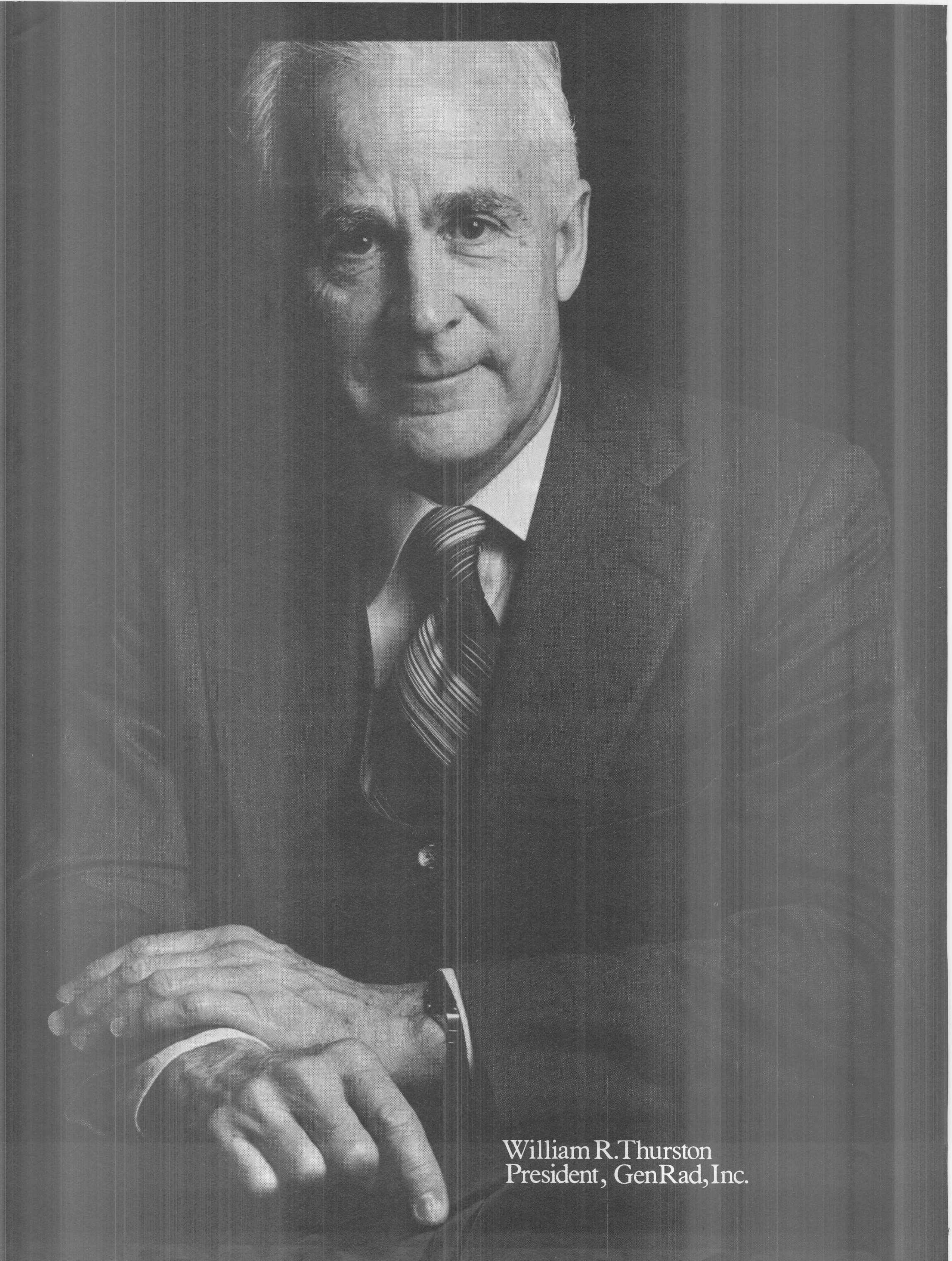
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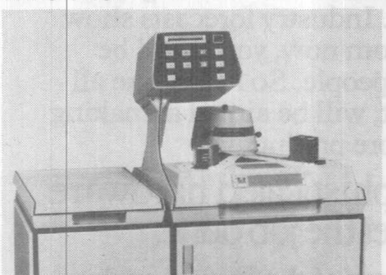

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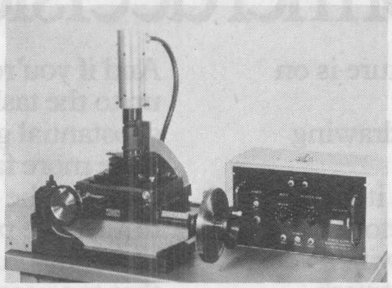

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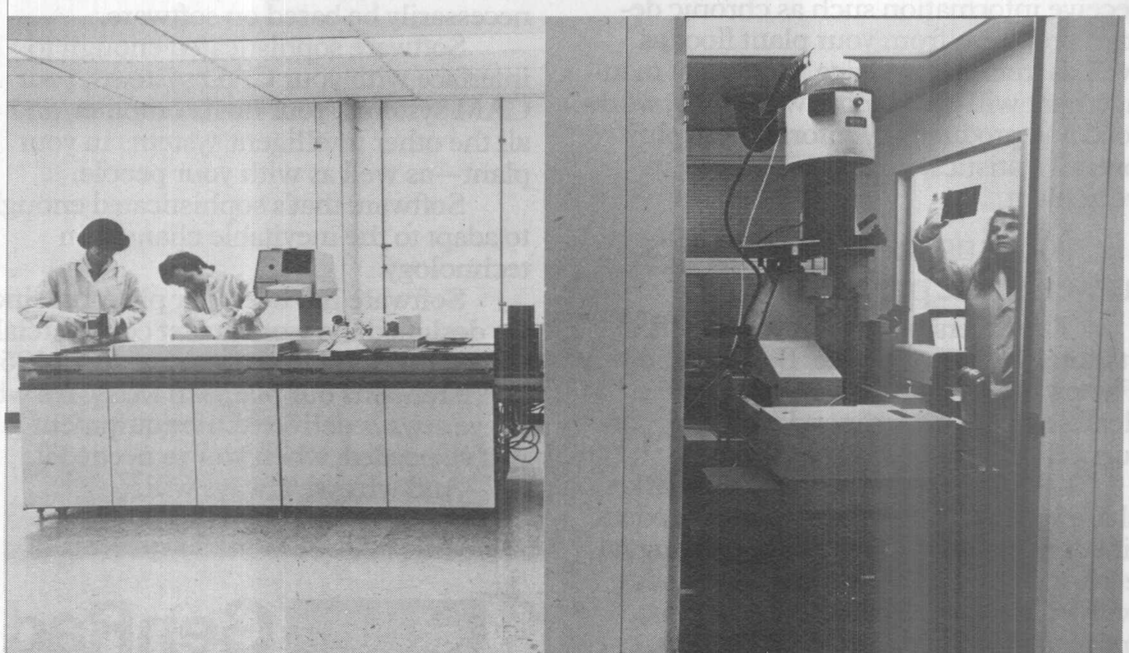


For the 1980's, GCA's DSW Wafer Stepper/Wafertrac, shown here interfaced, forms one of the most highly automated production systems for advanced device manufacture available today.

armed forces, the Office of Scientific Research and Development was set up.

This new organization correlated the committee's research program of the National Defense Research Committee with those of the military and the National Advisory Committee for Aeronautics. It also maintained close liaison with British scientists. It had under it 19 divisions, about half a dozen of which involved electronics. Bush was its director too, and subsequently also became director of the Joint Committee on New Weapons and Equipment, set up by the Joint U. S. Chiefs of Staff in May 1942, to introduce new weapons to the military.

One of the divisions that came under the Office of Scientific Research and Development served as the focal point of microwave radar R&D. In addition, Division 14 devoted major efforts to designing equipment that met specifically military problems and to making more effective use of equipment already on hand.

Radars were developed for aircraft detection, jamming, ship detection, weapon-fire control, navigation, and identification systems. Many were later to become fixtures in the civilian sector.

By 1940, Britain and the United States were trading radar secrets. The British Royal Radar Establishment under Robert (later Sir Robert) Watson-Watt had come up with the magnetron, a high-frequency electron tube that generated microwave energy. It operated in radar transmitters at S band (3,000 megahertz) and ultimately in most microwave radars of all frequencies ranging to 30,000 MHz.

Designers wanted the operating frequency to be as high as possible, since the radar's resolution—its ability to discriminate a single target among multiple targets—was better at the high end of the spectrum. Unfortunately, as the frequency went up, so did the atmospheric attenuation. This limited the range.

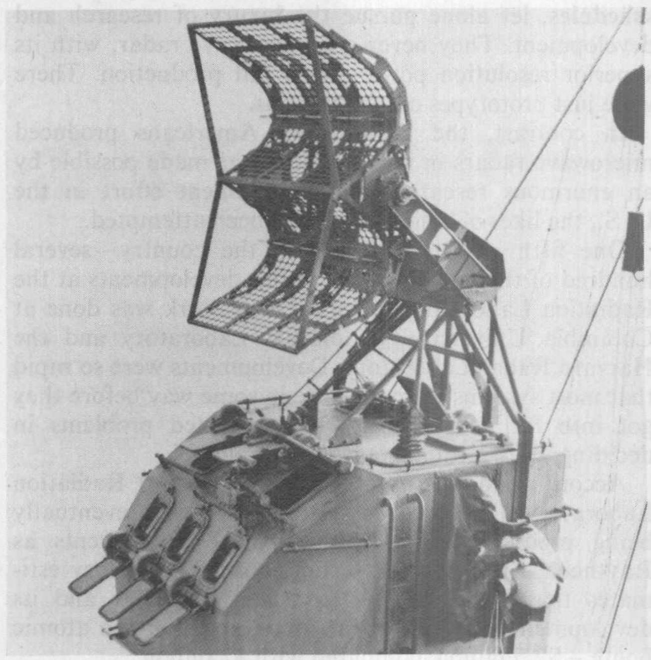
Nevertheless, the British achievement with magnetrons was notable. The Germans were never able to approach it; their radars were mostly limited to frequencies in the hundreds of megahertz.

In the U. S., researchers at Columbia University, the Massachusetts Institute of Technology, and the Naval Research Laboratory had come up with the duplexer. This switch let the radar transmitter and receiver use the same antenna. Both behaved better electrically, and the cost of a second antenna was saved.

Other world powers had also been active in radar. France had installed a megahertz-range pulse radar for collision avoidance on the luxury liner Normandie. This experimental device was put out of action when the Normandie caught fire and sank in 1942 while interned in New York Harbor. The Soviet Union was credited with an early-warning aircraft radar at 300 MHz in 1941, and Japan with a similar radar by 1942.

Unlike the British and Americans, the Germans, with their blitzkrieg tactics, did not plan their radar development programs for a long war. By the time they realized

warfare during World War II. This Mark 4 radar antenna is mounted on the Mark 37 gun director of the destroyer USS Nicholas (DD-449). This photograph was released in January of 1944.



Jammer. This antenna was designed by Harvard University's Research Laboratory as part of "Tuba"—a huge radar used by the RAF to blind the radar of German night fighters. Its shape gives a vertical and broad horizontal beam plane and wide frequency range.

that the conflict was not going to be over on schedule, it was too late. By then Germany itself was under bombardment night and day by the Allies, and the Germans found it hard to maintain current production schedules, let alone pursue the luxury of research and development. They never got microwave radar, with its superior resolution powers, into full production. There were just prototypes of new systems.

In contrast, the British and Americans produced microwave radars in volume. This was made possible by an enormous research and development effort in the U. S., the likes of which had never been attempted.

One fifth of all physicists in the country—several hundred of them—worked on radar developments at the Radiation Laboratory of MIT. Other work was done at Columbia University's Radiation Laboratory and the Harvard Radar Laboratory. Developments were so rapid that most systems were obsolete in some way before they got into full production. This presented problems in deciding when a radar was "good enough."

According to the 1946 "History of the MIT Radiation Laboratory," 2,000 radar sets a month were eventually being produced at such industrial establishments as Raytheon, Sperry, and Westinghouse. The history estimates that more money was spent on radar and its development than was spent to put together the atomic bomb—$2.5 billion, compared with $2 billion.

In combat, radar played the dual role of destroyer and defender. For Britain, it was a godsend. In July 1940 the Germans had begun an all-out aerial assault on Britain. They had 2,500 bombers and fighters to send to the attack; the Royal Air Force had but 900 fighters to oppose them. By the end of October 1940, the Luftwaffe was in retreat, beaten in the Battle of Britain.

British search radar, based on the work of Watson-Watt in the late 1930s, played a major role in the victory. With the radar, controllers on the ground were able to vector the RAF fighters to the right places at the right times. In one day in September 1940, Germany lost 185 planes in an attack on London.

Two different radars were responsible for the overall British success. One was the GCI, or ground-controlled intercept device; the other was the AI, or airborne intercept system. Both operated in the microwave range, with several versions using a 3,000-MHz magnetron. The GCI radars protected the home islands, while the AI were mounted in all the RAF fighter planes at frequencies through X band.

The 3,000-MHz radar, with a range of 50 miles or so, became the basis for many American designs from 1942 to 1945. With 300 MHz, the range was but 25 miles, and the radar had far less resolving power.

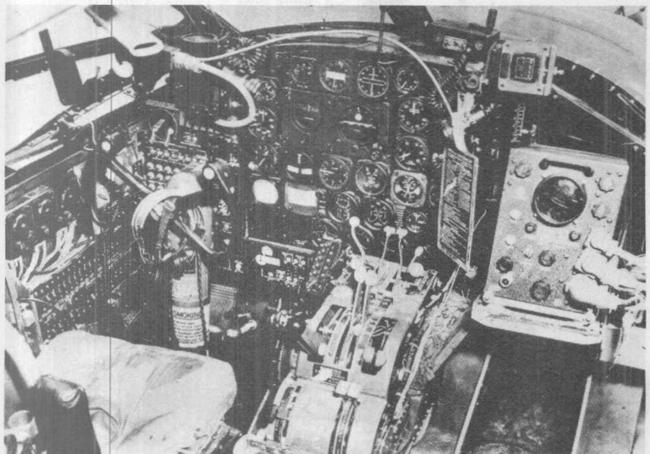
When Germany declared war on the U. S. on Dec. 11, 1941, a submarine-hunting radar, Dumbo-1, had just made its first flight on a U. S. naval patrol bomber. It was an outgrowth of the British AI. The AI also was the basic model for a U. S. fighter-plane radar.

Depending on the power available and the type of pulse that was transmitted, the useful range of the Allied radars was constantly changing. Early X-band types picked up information out to about 25 miles. On the other hand, one experimental American S-band set was operable out to 125 miles.

High-power tubes were a major source of interest for researchers at MIT's Radiation Laboratory because, besides increasing radar range, they could be used to jam enemy radars. Jammers were merely massive noise generators that, by brute force, overloaded the enemy receivers with strong signals.

For a time, lighthouse tubes—vacuum triodes that were megahertz extensions of classic radio-frequency vacuum tubes—were experimented with. One, the L-band Mark I radar, was developed at the MIT Radiation Laboratory and was the prototype for many later radars. But lighthouse tubes were mostly replaced by the more rugged and higher-powered magnetrons.

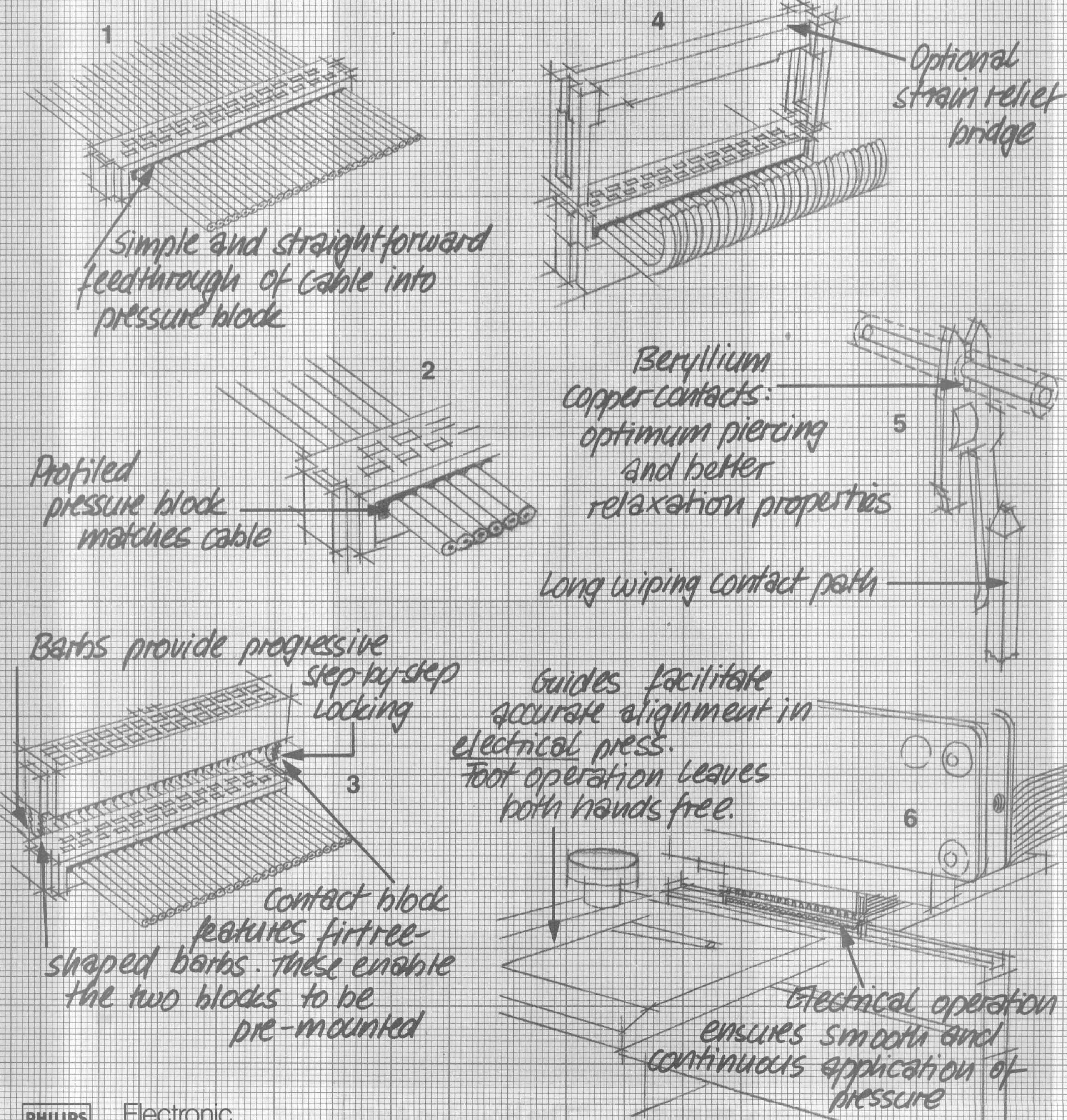
Production kept pace with radar research. Raytheon, for example, got a contract to produce several dozen S-band models, and soon the company was turning out



Cannon control. Cockpit of an Army A-26 fighter aircraft required a lot of squeezing in 1945 to be retrofitted with electronic gear. At extreme right is the Falcon M scope box, part of radar equipment used to direct fire of the 75-mm cannon, mounted below it.

Touchdown. This is an early Navy version of radar air traffic control. The operator directs the plane from azimuthal position scanned on scope in front of him. Meter on left indicates deviation from center of runway. Another meter, not visible, records elevation.

F 303: a mass of concepts... designed



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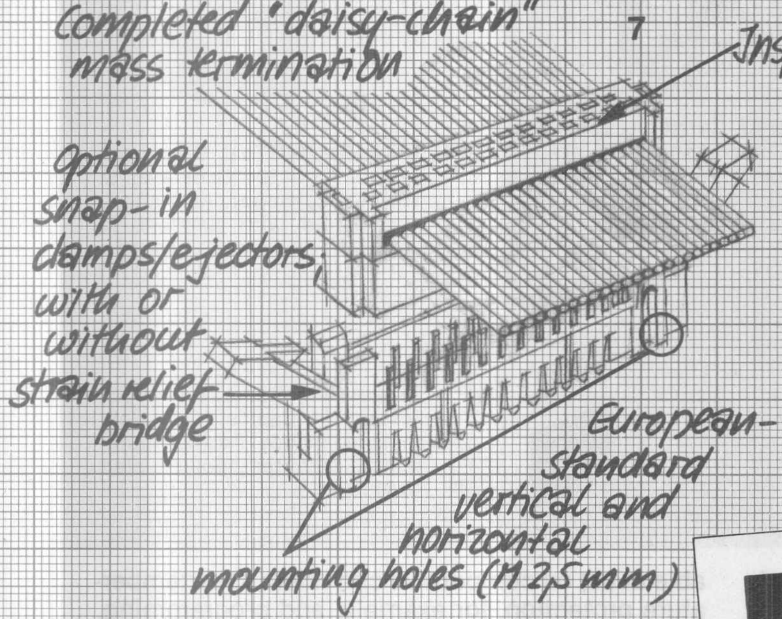

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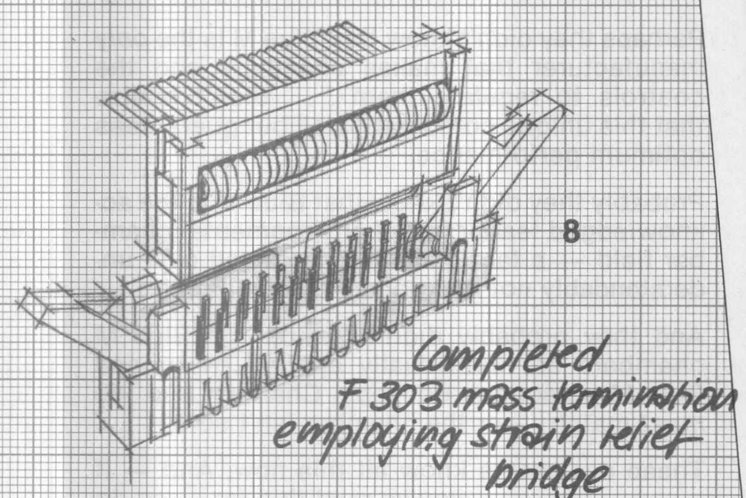
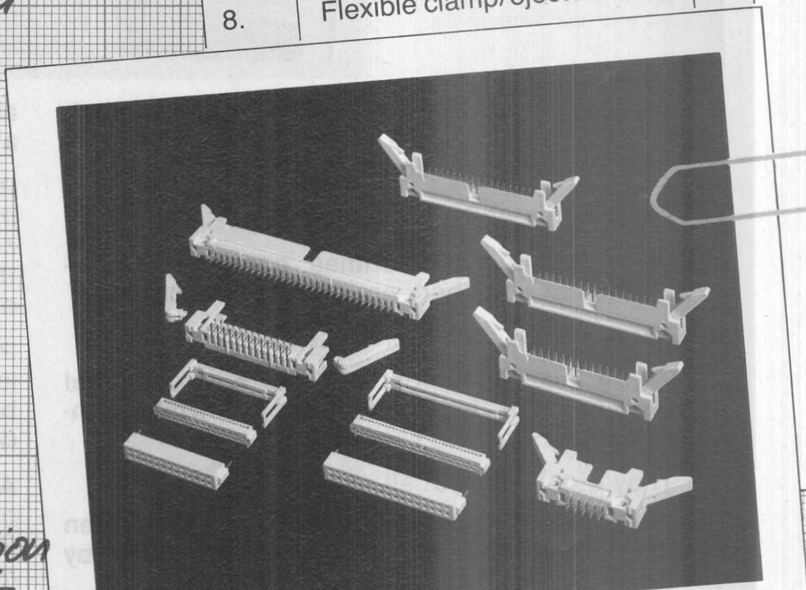
7.	European design	✓	
8.	Flexible clamp/ejector fitting	✓	





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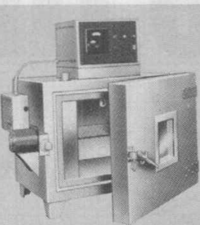

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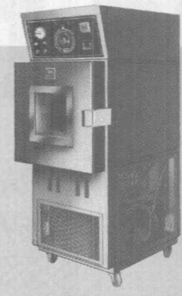

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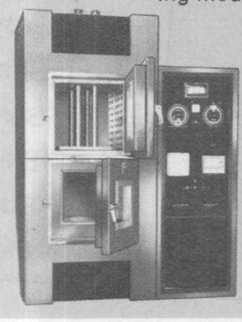

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magnetron. The user could vary the operating frequencies and thereby prevent the enemy from jamming.

Among the radar-jamming techniques developed throughout the war, one of the simplest and most effective was chaff. This was made of thin strips of aluminum or tin foil, cut to the right size for a given frequency. A large air drop of chaff could jam enemy radars by producing massive energy returns. If multiple frequencies were to be countered by the chaff, different sizes of metal were used. Chaff was cheap and easy to carry and did not have to be placed with any precision.

The antennas for radars were parabolic dishes, with the diameter determined by the operating frequency. The higher the frequency, the smaller the antenna diameter could be, so researchers had good reason besides better resolution to go to the highest possible frequency for airborne radars.

Careful control of antenna radiation patterns was essential for high resolution. If the antenna pattern was fuzzy, so was the image of the object displayed on the radar screen. One solution to this problem was the leaky waveguide antenna.

It consisted of a long run of waveguide—a hollow metallic pipe of circular or rectangular cross section—to guide the electromagnetic radiation. According to the theory, if holes were cut in the wall of the waveguide in places chosen by mathematical analysis—much of which was done by Julian Schwinger at MIT's Radiation Laboratory—energy would "leak out" and radiate in a controlled pattern. This could function as an antenna.

These devices could be hundreds of feet long, and in general they were not convenient to make or use. But they did work. Microwave frequencies were deemed especially suitable for this kind of transmission line, because they required fairly convenient waveguide dimensions. At X band the waveguide size was only 0.4 by 0.9 inch in cross section.

As radars became better able to discriminate multiple targets through the use of better antennas and frequencies, the problem of adequate display of the returned signals grew. At first a simple cathode-ray tube—much like the one in an oscilloscope—was used. But advances were quick in coming.

The first airborne radar plan position indicator (PPI), designed at MIT's Radiation Laboratory, was installed in July 1942 in a Navy Lockheed patrol bomber. With two coordinates—range and bearing—displayed on the screen, the operator could track enemy submarines more accurately.

Radar resolution and the PPI developed to such an extent that operators could take radar "photographs." Under ideal conditions, the shadow shapes of approaching aircraft could be seen and identified.

At this time a British visitor to the MIT Radiation Laboratory saw a PPI display of Nantucket Island. It was so like a photograph that he was quoted as saying: "This is a turning point in the war." It was the CXBK radar—a search device at X band with a range of over 100 miles.

From this point on, the use of filters grew rapidly, and they soon were being used to reduce jamming signals.

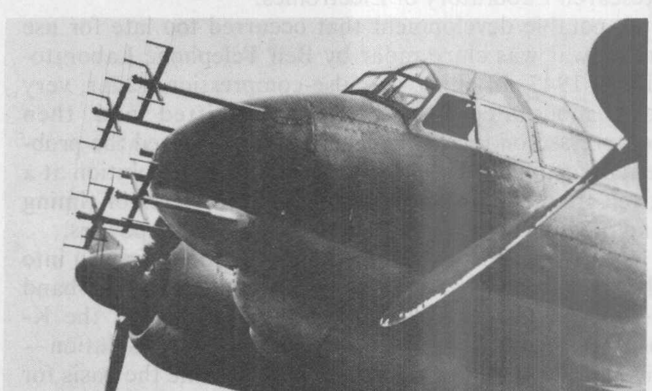
By 1943 the Axis powers were tasting defeat regularly. And electronics had helped to turn the tide. At the Radiation Laboratory, a prototype of the MEW—a microwave early-warning radar that could look out to 150 miles or more and detect and resolve several dozen targets—was built in a few weeks after its initial design. Some facts about the MEW are still classified. It used a high-power magnetron at S band, and years later, in the 1950s, it formed the basis for the U. S. early-warning radar system installed in Canada.

Another major radar development that came to the fore in 1943 was the H2X. At first merely experimental, it turned out to be so good that it was put into production on a crash basis. A radar transmitter that allowed for precision bombing in bad weather—to within 100 yards in some cases—it was installed in the nose section of B-17 bombers and used to drop bombs over Germany.

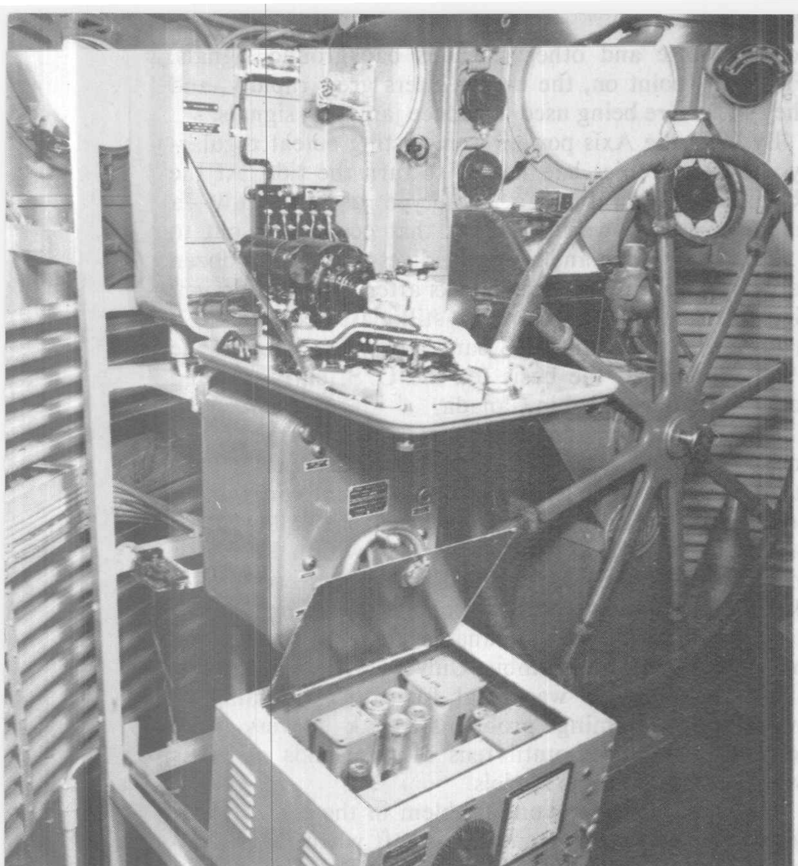
A late version of a tunable X-band magnetron emerged from the Columbia University radar group at about this time. It was ideal for either jamming or overcoming jamming problems. Peak powers were constantly improved until tens of thousands of watts were available in some models.

Throughout the war one problem in the use of radar was the detection of incoming aircraft when the attackers hugged the ground. A phenomenon called ground clutter, or returned radar noise from the ground, sometimes masked the low-flying smaller planes. This effect was under constant study and ways were found to minimize it, which included varying the radar frequency and type of pulse. The difference in the echoes received under these varying conditions allowed for a certain amount of what is now called signal processing to reduce the effect of the clutter. Much of this work was done at MIT's Radiation Laboratory.

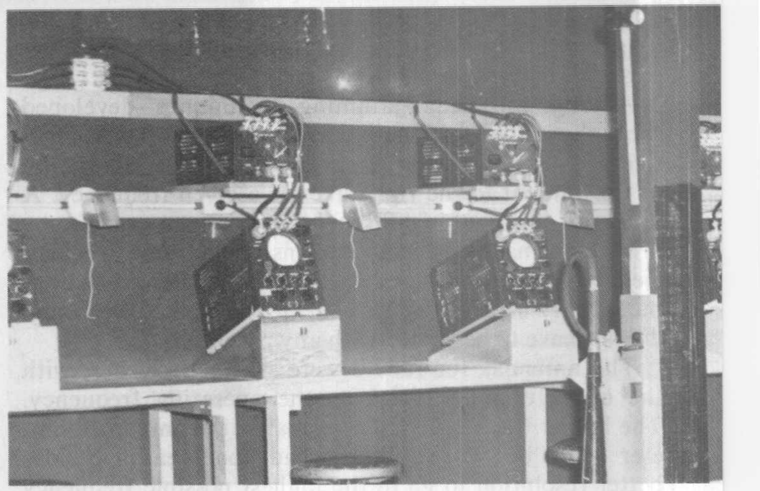
As the war neared an end in 1945, radar research and the design of new models slowed. Basic research contin-



German radar. Antenna arrays built into the nose of this German plane are part of the airborne radar equipment used by the pilot to find his target during nighttime operations. Jamming from ground installations like Tuba proved an effective countermeasure.



Antisub. In 1944, when this installation was photographed, sonar technology had enabled the Allies to greatly reduce the huge losses of shipping to German submarines. Such systems were capable of determining a submarine's depth and could track its movement.



ued in many laboratories. The Radiation Laboratory at MIT had established a Basic Research division under Julius A. Stratton, with the goal of transferring wartime research results to the civilian sector. Studies on gaseous conductors, dielectric materials, and basic physics were projected, and this work was taken over by the institute's Research Laboratory of Electronics.

A notable development that occurred too late for use in the war was chirp radar by Bell Telephone Laboratories in 1947. In chirp, or pulse-compression, radar, very long modulated pulses are transmitted and then compressed on reception. This approach solved the problem of attaining both long range and high resolution at a given frequency, while avoiding the problems of timing and of generating short pulses with high peak powers.

Other wartime developments that made their way into the commercial sector included the APS-10, an S-band airborne radar that ended up in airliners, and the K-band MK-26 radar, which had such high resolution—rivers could be clearly seen—that it became the basis for radar mapping.

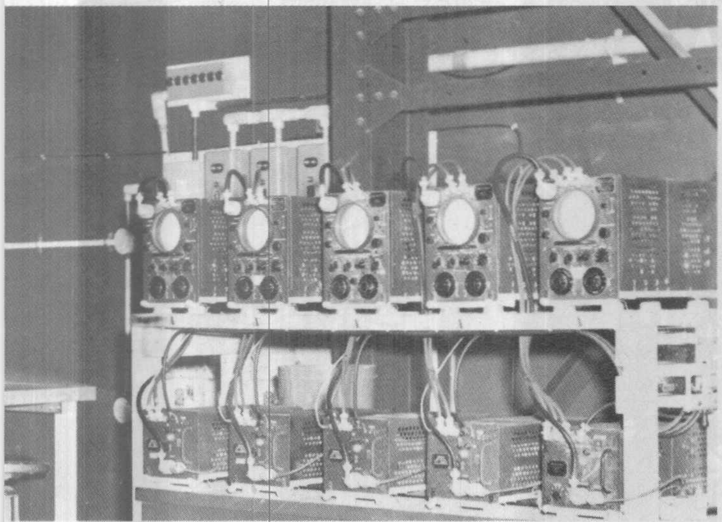
Radar had indeed been the stimulus for the frantic pace of tube developments, and the magnetron's progress from a laboratory experiment to a dependable high-frequency source was a major success story. A less publicized development was the design of the transmitter-receiver tube. This was a switching tube, usually gas-filled, that protected the radar receiver input when the transmitter pulsed. It allowed radio-frequency echoes from the target to reach the receiver between pulses.

Most significant of all was radar's use of crystal rectifiers as mixers, video detectors, and dc restorers. The wartime crystal rectifiers were not the crude cat's whisker galena units of the 1920s and 1930s but sealed leaded types. Germanium crystals were most heavily used, and units at this time could withstand 50 V dc. Forward resistance was about 0.1 ohm. The diodes were applied up to frequencies of 3,000 MHz.

With the merging of British and U. S. research efforts, the two countries soon realized that their work on sonar was proceeding along almost parallel paths. One difference was that the British were working with a quartz-steel (electrostrictive) transducer to send out the system's sound waves, whereas the U. S. was developing a transducer that used magnetostriction to emit "pings." Sonar, employed to locate submerged enemy submarines, derives from the words Sound Navigation And Ranging. Like radar, it is an echo-ranging device.

To summarize its basic principles, a ship sends a sound wave into the water. Encountering an obstacle, the wave is reflected back to the ship, which—since the speed of sound through water is known—determines its distance from the object from the time it took the echo to return. To create the original sound wave, the ship generates electrical signals in a transmitter; it then sends these to a transducer, positioned on its keel as deeply in the water as possible. The transducer converts the signals into sound and transmits them through the water.

The British traced their sonar system to World War I, when a piezoelectric oscillator was used to emit the sound waves in a system called the ASDIC, named for the Allied Submarine Detection Investigation Committee, set up in 1917. At the outbreak of World War II, Britain outfitted its fleet with ASDICs that had the quartz-steel transducer. In the U. S., meanwhile, work on the magnetostriction-tube transducer was being done under contract by the Submarine Signal Co. of Newport, R. I.



Navigation. Another contribution of the MIT Radiation Laboratory to the war effort was loran, a system by which vessels could determine their true position very accurately. This early installation (circa 1945) was at the Naval Air Station at Whidbey Island, Washington.

(which has since been acquired by Raytheon).

Once the U.S. entered the war, cooperation led to improvements in both systems: the Americans used a streamlined transducer dome from the British ASDIC, and the British adopted the American transducer.

From 1941 to 1943 there were heavy Allied shipping losses to submarines, but thereafter sonar-equipped escort ships were effective in protecting merchant marine convoys in the Atlantic. Sonobuoys dropped from aircraft supplemented this effort. Echoes from enemy submarines were picked up by the sonobuoys, which relayed the information to the aircraft so they could direct attacking warships to the submarines.

Other instruments appended to sonar made the system capable of detecting submerged minefields, determining a submarine's depth, and providing an indication of oncoming torpedoes.

When the Allied forces landed in Normandy in 1944, the combination of air cover and tight radar and sonar screens so protected the invasion force that no ships were lost to enemy submarines.

Not as critical to the war effort as radar or sonar, loran (Long-Range Navigation) emerged from the Radiation Laboratory of MIT as somewhat of an electronic frosting on the cake. The concept called for one master station and two slave stations 200 to 500 miles away. In MIT's plan, the master transmitter would send a pulsed signal that, upon arrival at one of the slave stations, would trigger a similar pulse from that station on the same frequency. An operator could obtain a direct time-difference reading at the sender's receiver by matching the pulses from the master and slave stations, and a family of hyperbolic curves could be constructed from the time differences.

A second slave station at a third location would be similarly triggered by the master station. The signals from the first master-slave pair would be distinguished from the second pair by their different pulse-repetition rates. With a second family of hyperbolic loci, the longitude and latitude of a target could be determined.

In October 1942 the first experimental loran station covering the Atlantic seacoast from Delaware to Nova Scotia was made operational. Its range was 300 to 800 nautical miles during the day and 1,500 nm at night. It was designed to provide a fix accurate to within 1% of a vessel's true position in the 300-to-800-nm range, called the primary area, and accurate to within 5% in secondary areas, defined as 1,000 nm or more away day or night. Using pulsed transmissions to eliminate "night effect"—sky-wave refractions and reflections of the signal that created errors in measurement at the receiver—loran covered the heart of the 160-meter amateur band, much to the chagrin of many ham operators. But under wartime conditions all amateur activity had been outlawed anyway. Nevertheless, loran retained its frequency assignment after the war, and it remains in the amateur band to this day, although it will soon be replaced on a wide scale by loran C, operating at a frequency of 100 kilohertz.

Spurred by the success of loran, researchers came up with other systems. One was the GEE system, which worked on principles similar to those of loran but over the experimental operating frequency of 20 to 85 kHz. The transmission characteristics of this band were found to be invariant to all disturbances, natural and otherwise.

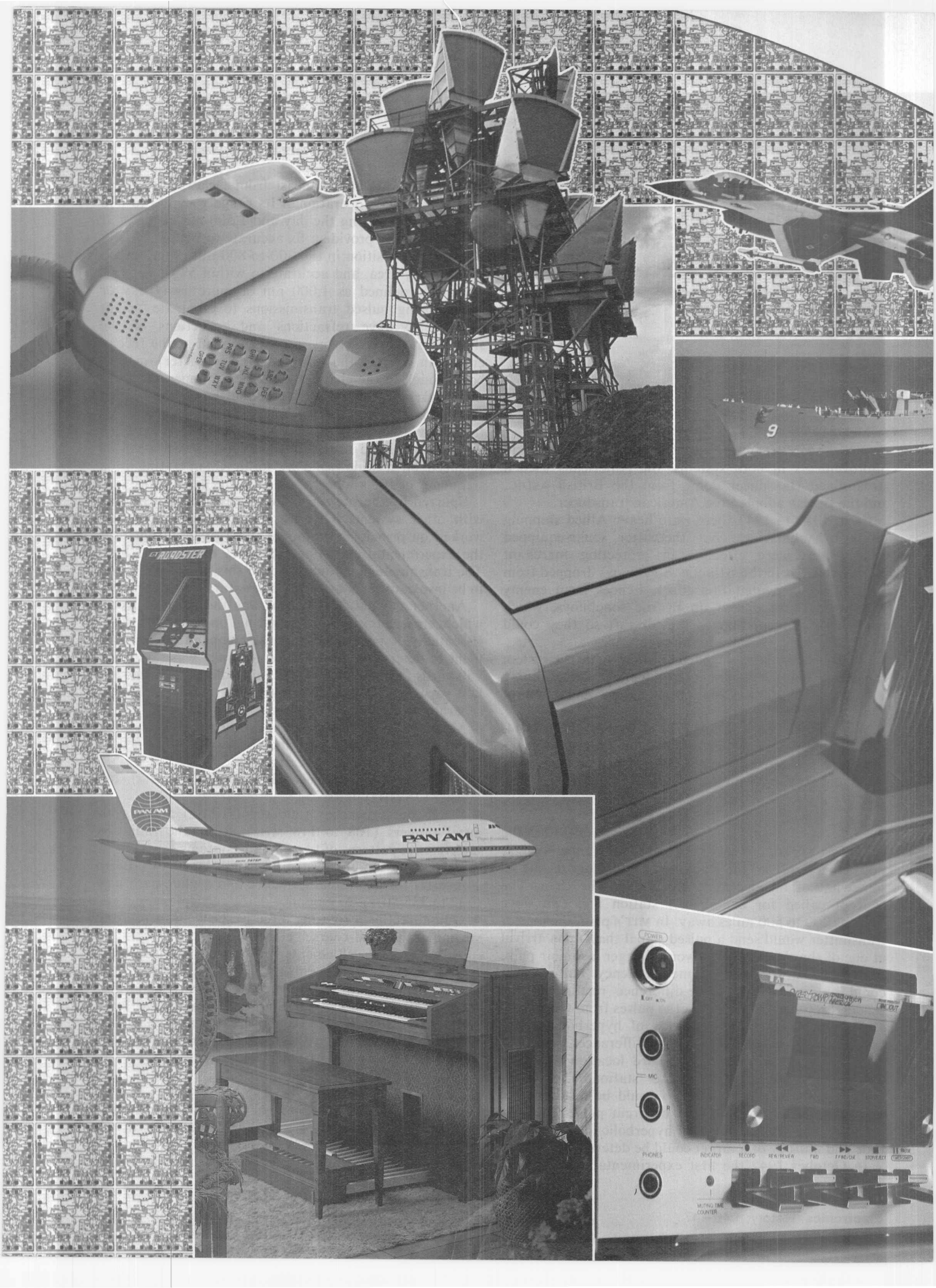
Another navigational system was the British Decca, which emerged in 1946, operating on 75 to 85 kHz. Essentially it performed a phase-comparison measurement to determine position. Its accuracy was said to be 150 yards at a distance of 250 miles during the day and 800 yards at 250 miles at night, but it required three separate receivers.

Meanwhile, other short-range beacon systems, built upon both old and new principles, were developed in quantity. There were four categories.

- Fixed beacon, using both homing (1,750 kHz) and marker (75 MHz) units.
- Fixed-course beacons (200 to 400 kHz) and visual-aural rangers (108 to 118 MHz), using the radiation interference patterns of two antenna systems.
- Instrument landing systems, using a localizer (108 to 112 MHz) for azimuthal guidance and a glide-path unit (332 to 335 MHz) for guidance in the vertical plane.
- Omnidirectional rotating directive beacons, a rotating version of the fixed-course beacon types.

All of these developments helped pave the way for a revolution in navigational techniques after the war. During the war both sea and air navigators relied largely on sextant sightings of the stars and planets for long-range navigation. Closer to home, radio figured prominently in determining position. But after the war, the push was toward all-electronic navigation.

One of the great contributions of World War II research and development was that it broke ground for the electronics industries' long drive toward miniaturization. There had been efforts in this



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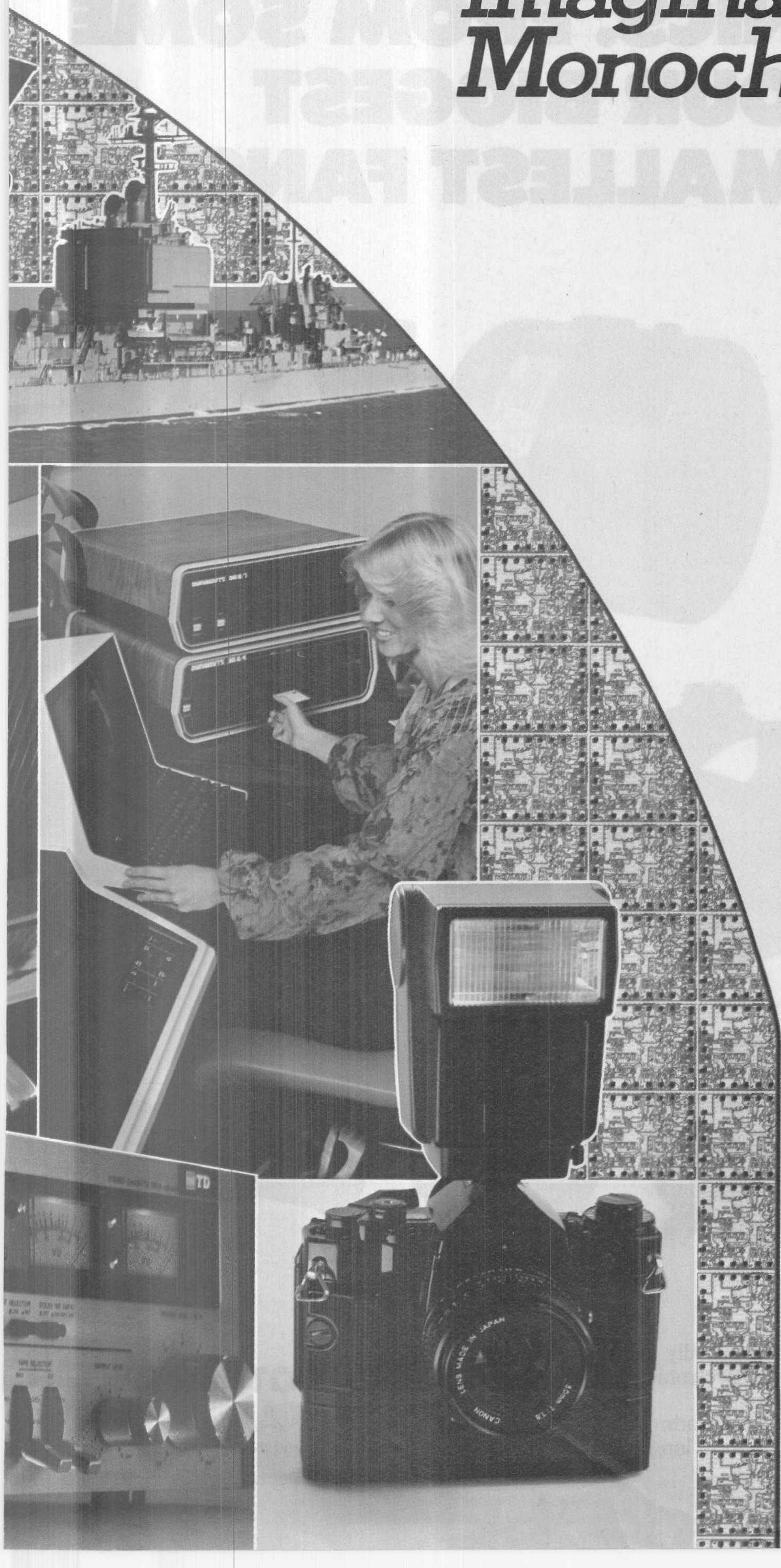

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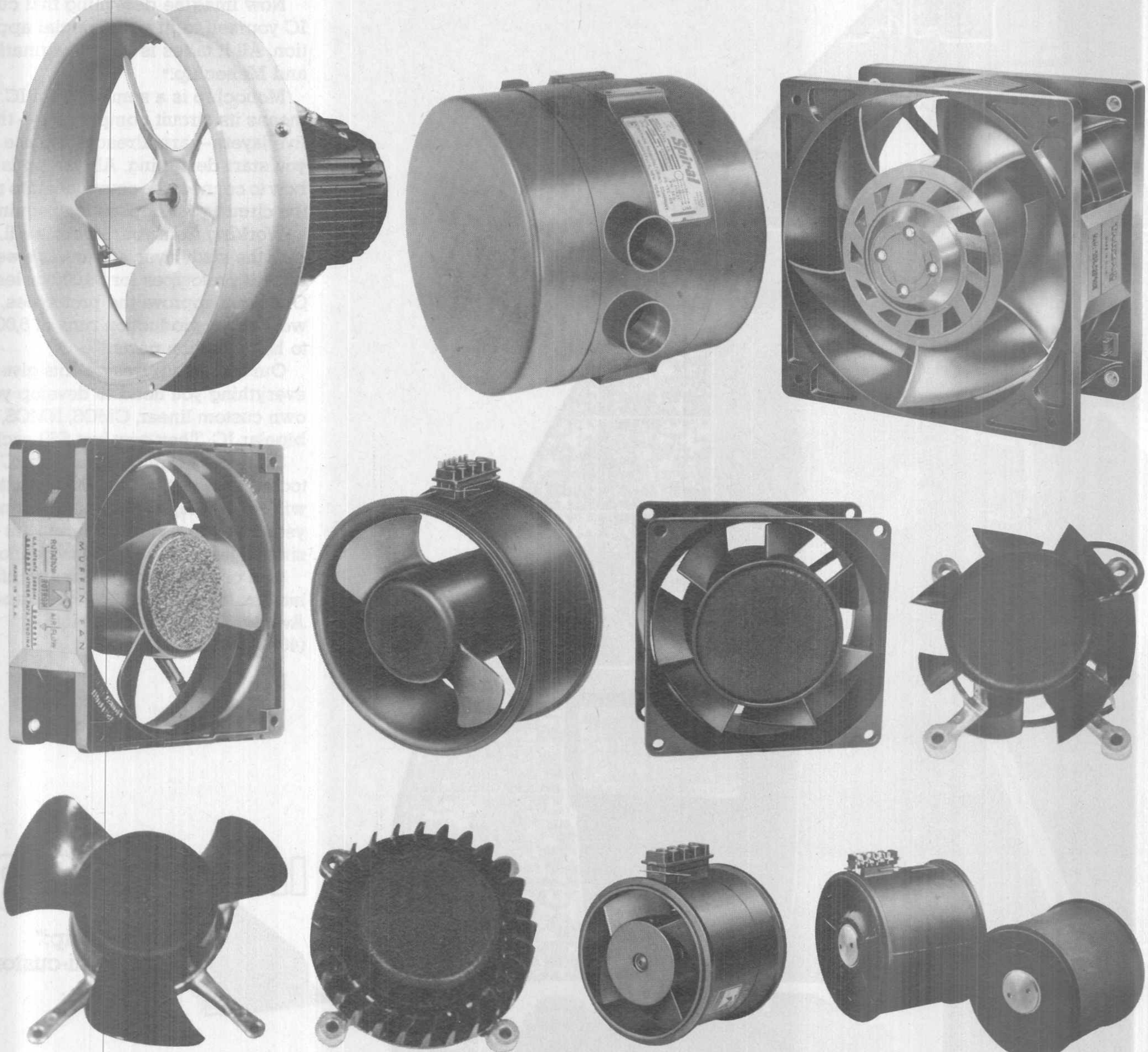

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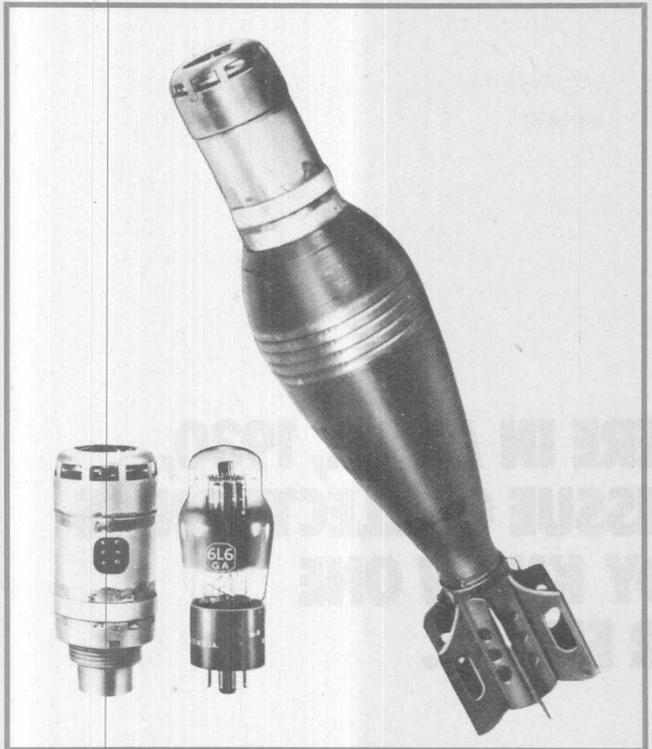


Microminiaturization's debut. The proximity fuze, shown here mounted on an 81-mm mortar shell, required radically new techniques for producing ruggedized miniature circuitry, such as screening and firing components on ceramic substrates.

direction with the making of hearing aids, but the wartime effort to develop the proximity fuze provided the discipline and urgency that set the stage for the present integrated-circuit era.

American work on variable time fuzes had been under way for a decade before World War II at the Navy's Bureau of Ordnance. The bureau wanted a projectile that did not have to score a direct hit but could be detonated in the vicinity of its target—as close as possible, to cause maximum damage from shrapnel. Time fuzes were available, but they had to be set by hand before the projectile was fired, and they could not compensate for evasive maneuvers by the target—enemy aircraft, say.

The proximity fuze was electronically operated. It used a miniature transceiver that radiated a highly directional rf beam at its target and was detonated by a strong return from the target. The fuze was used in artillery and mortar shells, rockets and bombs.

The major problem, of course, was building a tiny transceiver that could withstand the shock of being shot from guns. Among receiving tubes, designs allowing operation directly from a 24-volt battery had been developed for airborne use. These tubes had 26.5-V filaments and 28-V plate and screen operation. The tubes had been ruggedized to withstand vibration and to take up to 500 g of acceleration. But it was to subminiature tubes developed for hearing aids that the fuze researchers turned, and eventually a hearing aid tube, rated at 20,000 g, became the heart of the proximity fuze.

In the summer of 1940 it had become apparent that the British were also working on a proximity fuze, because they had placed large orders in this country for vacuum tubes and photelectric cells of the types being investigated by the U. S. Navy. The two countries pooled their research efforts.

Eventually one third of the electronics industry in the U. S. became involved. Manufacturing capacity for tubes, capacitors, and resistors was tremendously increased. The cost of the project approached $1 billion, and over 20 million expendable fuzes were produced.

Fortunately for the Allies, the Germans had done research on proximity fuzes before the war but had failed to develop ruggedized subminiature tubes.

Two types of proximity fuzes were produced for the Allies: a wind-powered generator unit and a battery-powered unit. The wind-generator fuzes ended up in airborne rockets and bombs. The battery-powered circuitry was housed in the casing of antiaircraft (AA) artillery shells.

No chassis was used in the construction of the AA fuzes. The tubes were mounted in close-fitting rubber cups near the center of the electronic bundle. Resistors and capacitors were then wired together in subassemblies and wrapped around the central rubber cups containing the tubes. After all the connections were made, the electronic parts were placed in a plastic nose in the shell and all air spaces filled by potting with wax. This was one of the first instances of potting of electronic equipment in the U. S.

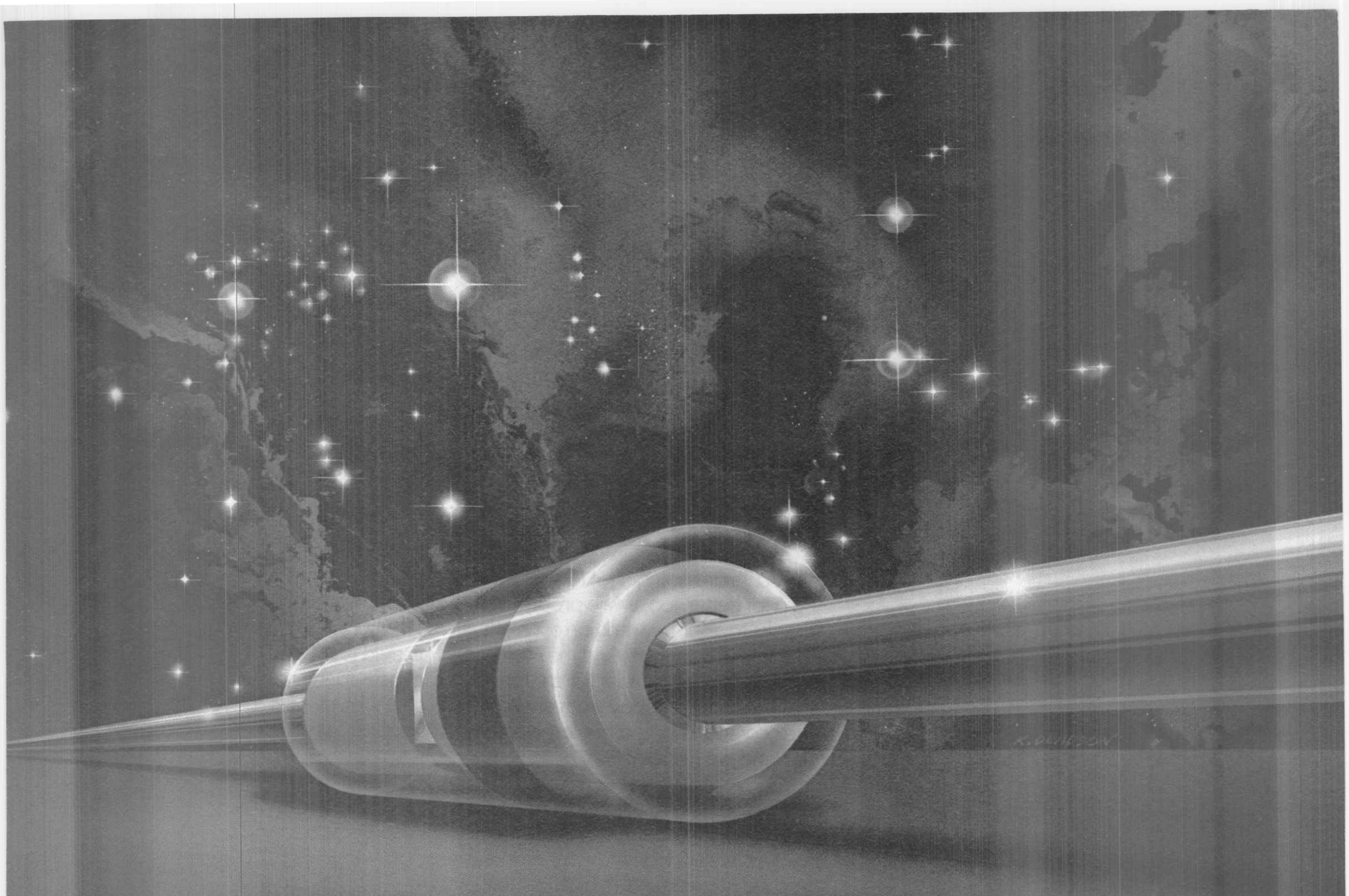
The first use of proximity fuzes at sea occurred on Jan. 5, 1943, when gunners on the U. S. cruiser Helena knocked down a Japanese dive bomber near Guadalcanal with their second salvo. The following month an American troop convoy was attacked at night in the same area by 12 Japanese torpedo bombers. The convoy was defended entirely by radar-controlled antiaircraft guns using proximity fuzes. Five of the attackers were shot down, and there were no enemy torpedo hits. In the European theater, crewmen on the American destroyers Swanson and Roe used proximity-fuzed shells to knock down a German J-88 dive bomber in July 1943 in one of the earliest uses in that region.

Proximity-fuzed rounds fired in action in 1943 were said to be three times as effective as time-fuzed ammunition aided by the latest radar fire control, and from 1944 onward the use of the proximity fuze became standard. It was credited with helping to turn back the Japanese kamikaze assault on the U. S. fleet off Okinawa in 1945.

The British, meanwhile, used proximity-fuzed ammunition to help counter the German "buzz bomb" attacks on London in 1944. Antiaircraft batteries, moved to the English coast, increased Britain's kill rate of the German missiles from 24% during the first week of the attacks to 79% by the time the attacks subsided 11 weeks later.

The proximity fuze was unquestionably a success. Calculating the trajectories of wartime projectiles raised another problem.

While business and scientific calculations had stimulated early computing developments in the United



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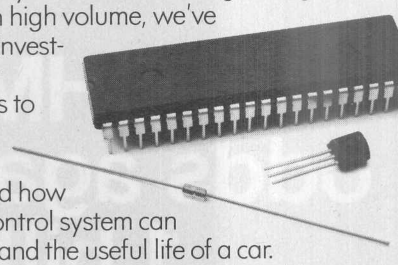

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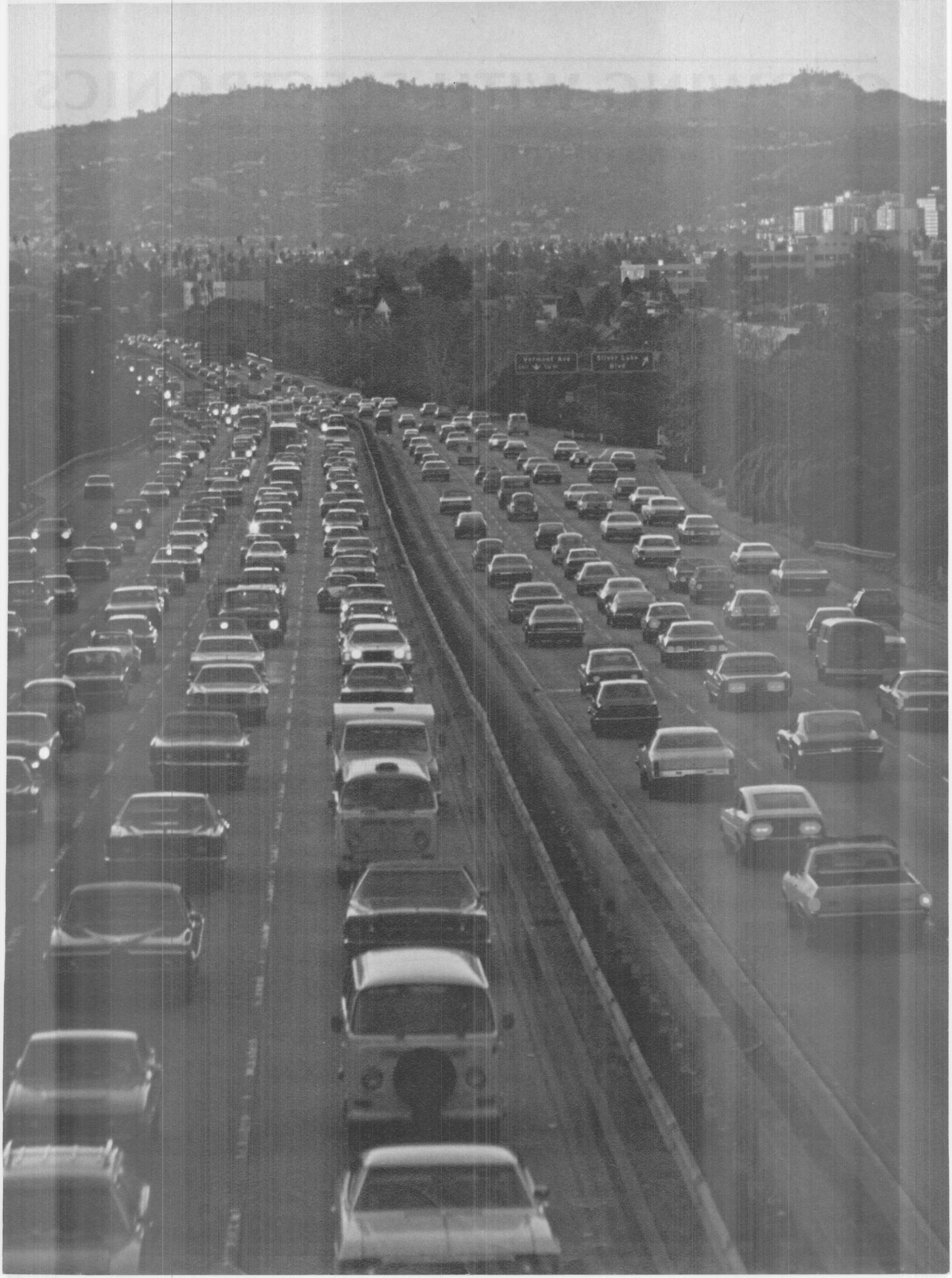
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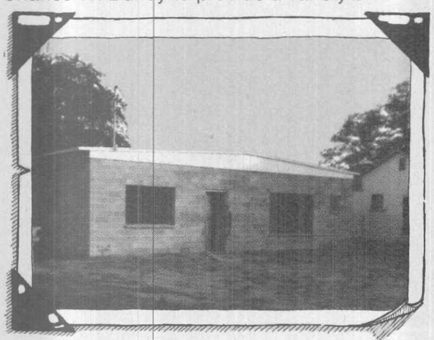

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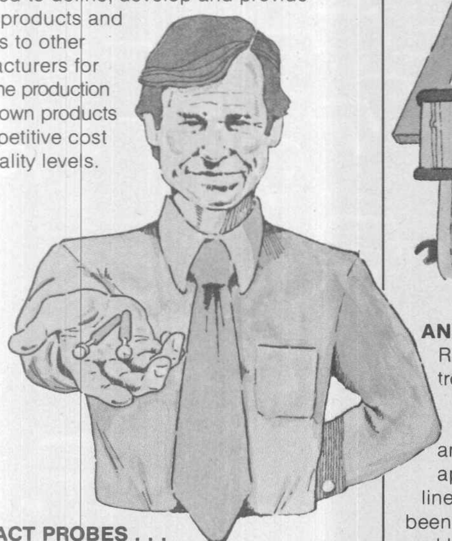

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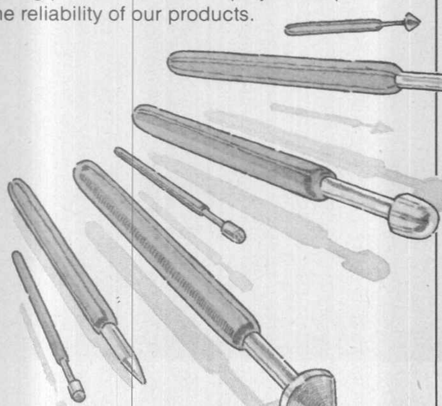

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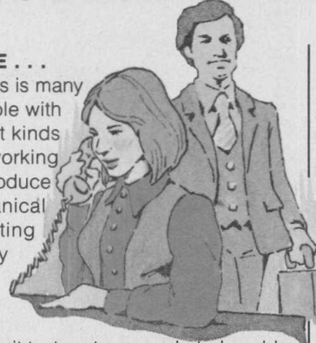

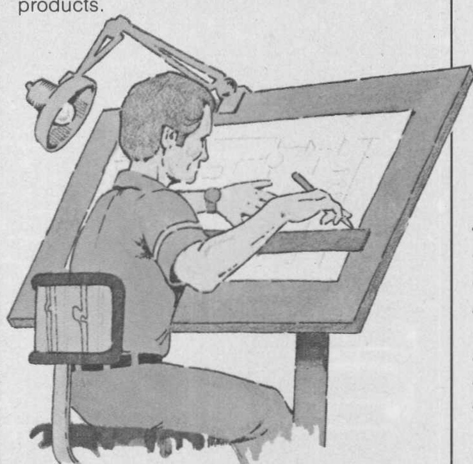

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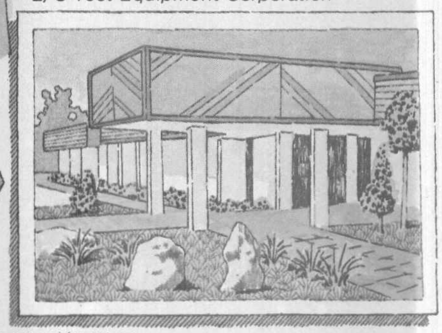

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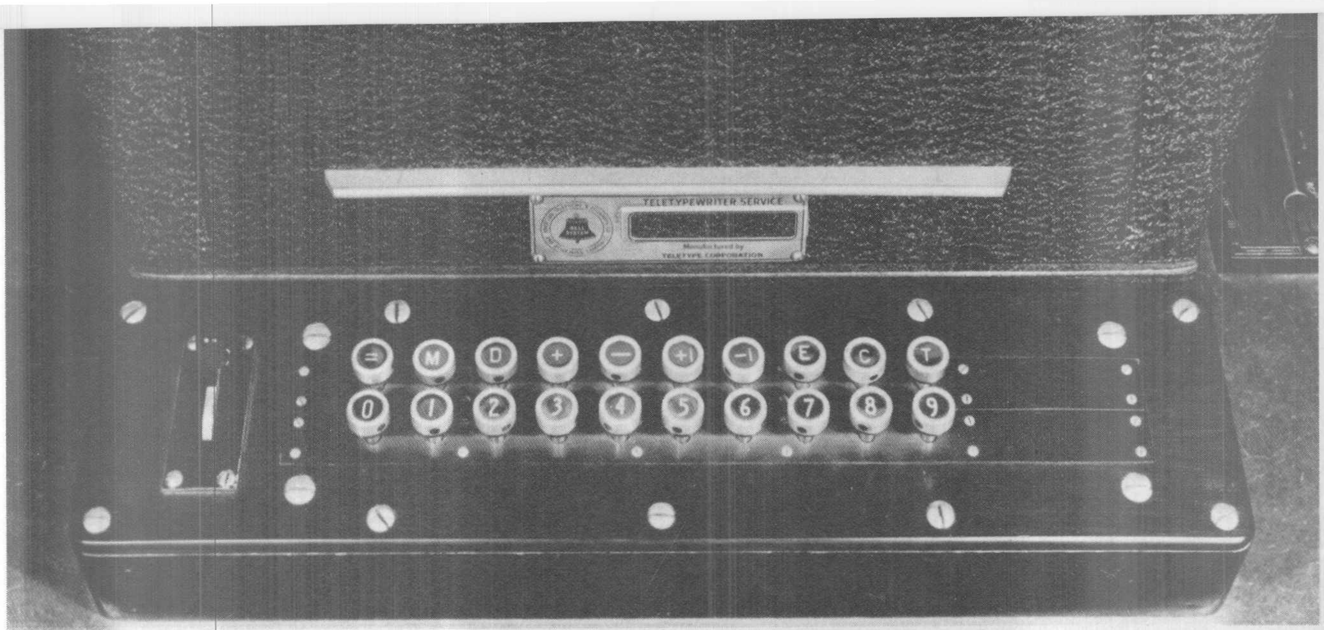


Early computer. This keyboard belonged to the first Bell Laboratories relay computer, which was put into operation in 1940 at the laboratories' old West Street facility in New York City. It was for this computer that binary-coded decimal notation was developed.

States, it was weapons research for World War II that proved to be the catalyst in the creation of the electronic digital computer.

Calculating the trajectory of projectiles had become more complicated as their velocity increased, and the advent of aerial warfare had added the task of performing these calculations rapidly enough to aim antiaircraft guns at fast-moving targets. Dropping bombs from aircraft required similar rapid calculations.

To develop both the weapons and better ways to compile firing tables, which contained the various trajectory calculations, the Army's Ordnance Department had created a research division at the Aberdeen Proving Ground in Maryland in 1935. Renamed the Ballistic Research Laboratory in 1938, it was headed from the beginning by Herman H. Zornig, who chose Oswald Veblen to serve as chief scientist throughout the war.

Zornig also established a Scientific Advisory Committee to help him. It was composed of leading American scientists, including Hugh L. Dryden, an aerodynamicist and later founder of the National Aeronautics and Space Administration; Albert W. Hull, a prolific inventor of electron tubes; Theodore von Karman, another aerodynamicist; Bernard Lewis, a physical chemist; John von Neumann, the mathematician; Henry N. Russell, an astronomer; Isador I. Rabi, a Nobel Laureate in physics; and Harold C. Urey, a Nobel Laureate in chemistry.

One mathematician who joined the Ballistic Research Laboratory between 1941 and 1942, Herman H. Goldstine, noted later that the typical trajectory computation required some 750 multiplications. But to compile the average firing table, taking into account the various angles, muzzle velocities, and other conditions, one had to contend with the calculations for between 2,000 and 4,000 of these trajectories.

Goldstine estimated that a human being with a mechanical desk calculator of the day would take 10 seconds to perform a multiplication and therefore need some 2 hours to do the multiplications and a total of 12 hours to calculate a single complete trajectory. But the mechanical differential analyzer, operating at between 1.6 and 4 seconds per multiplication, took some 10 to 20 minutes per trajectory, or 750 hours—30 days—to do the trajectory calculations for an entire table.

At MIT in 1942, Vannevar Bush and S. H. Caldwell completed a differential analyzer that replaced the machine's usual mechanical shafts with electrical connections. This allowed them to use a punched paper-tape reader to reconfigure the machine for various problems, thereby speeding its operation.

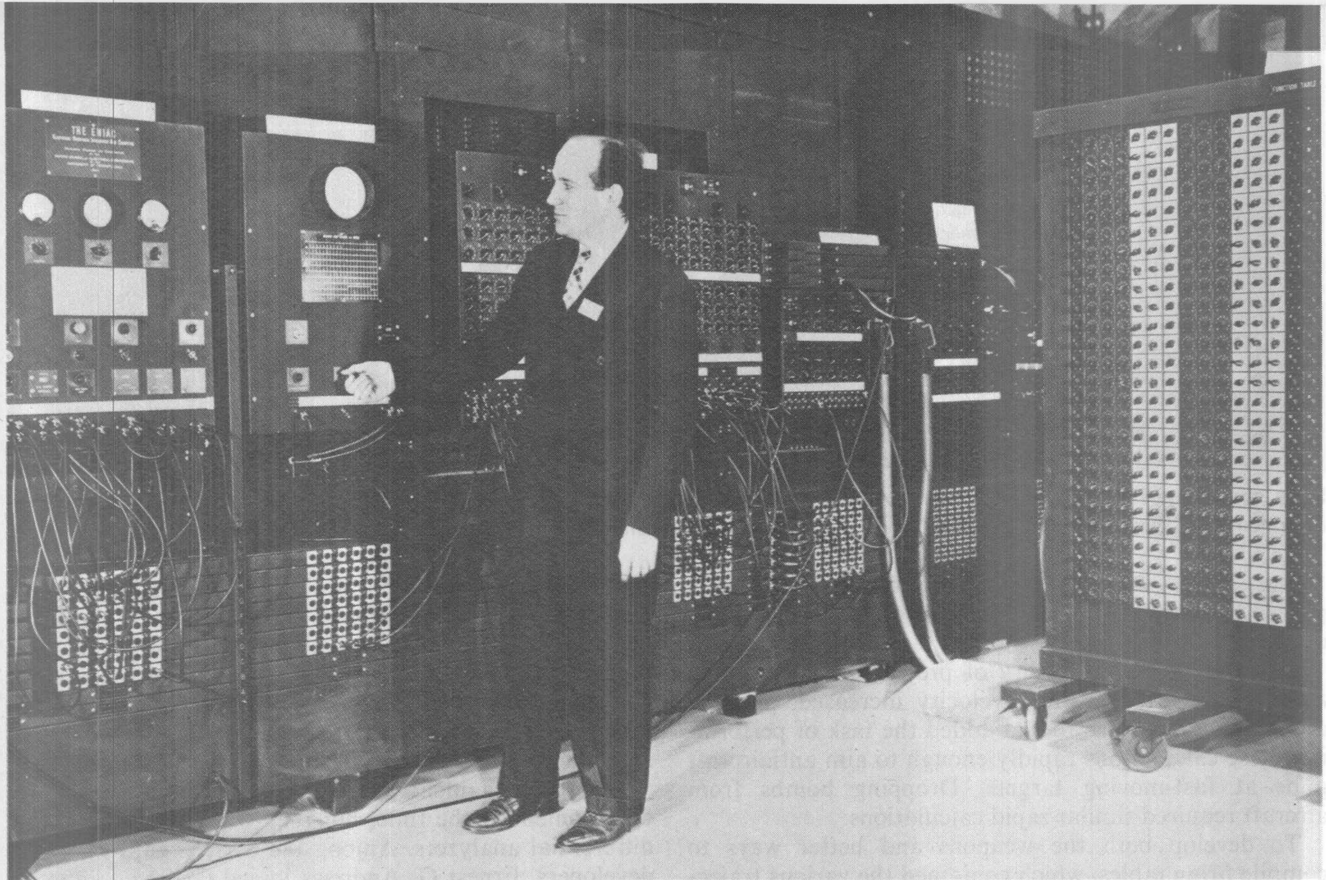
Electromechanical digital computers were under development at the time, but they were slower than the differential analyzers. Among the early digital machine developers, Ernest G. Andrews joined George Stibitz at Bell Telephone Laboratories, where two relay computers, the Model II and Model III, were finished.

The Bell Model III, the larger of the two, was completed in 1944. Using some 9,000 relays for all operations and registers, it covered about 1,000 square feet and was estimated to weigh 10 tons. The addition of numbers of up to 7 decimal digits took 300 milliseconds, their multiplication took 1 second, and their division 2.2 seconds. The machine took 40 minutes to compute a trajectory.

The Automatic Sequence Controlled Calculator, Howard Aiken's machine under development by International Business Machines and Harvard University (see chapter 3) was also finished in 1944 and delivered to Harvard. Measuring 51 feet long and 8 feet high, it contained some 800,000 parts and offered 60 registers for constants, 72 storage registers for addition, a central multiplication and division unit, and the ability to compute elementary transcendental functions, such as logarithms and sine.

Later known as the Mark I, it could handle 23-decimal-digit numbers and perform additions in 0.3 second and multiplications in 3 seconds. The Harvard-IBM Mark II, the successor to Aiken's Mark I, working with 10-digit numbers and a multiplication time of 0.4 second, took about 15 minutes to do a trajectory.

The University of Pennsylvania's Moore School of Electrical Engineering at Philadelphia had been working with the Army and the Ballistics Laboratory on trajectory calculation problems since the 1930s. J. Presper



New era. The age of the electronic digital computer was ushered in with the dedication of Eniac at the University of Pennsylvania in 1946. J. Presper Eckert (above), with John W. Mauchly, supervised the design and construction of the system, intended to solve ballistic problems.

Eckert, a graduate student at the school when World War II began, recalls the task posed for the school. "The Moore School," he says, "trained some 300 people to use calculators to solve the ballistic problems. Every closet you opened had a woman with a calculator."

Also at the school was Prof. John W. Mauchly, who recalled that he "was impressed with the differential calculator but realized its limitations." He first discovered what a burden computing could be "when I took a course in statistics." Although the calculations took hours, he realized that statistical analysis would be a useful tool in many areas of science, particularly meteorology and weather prediction.

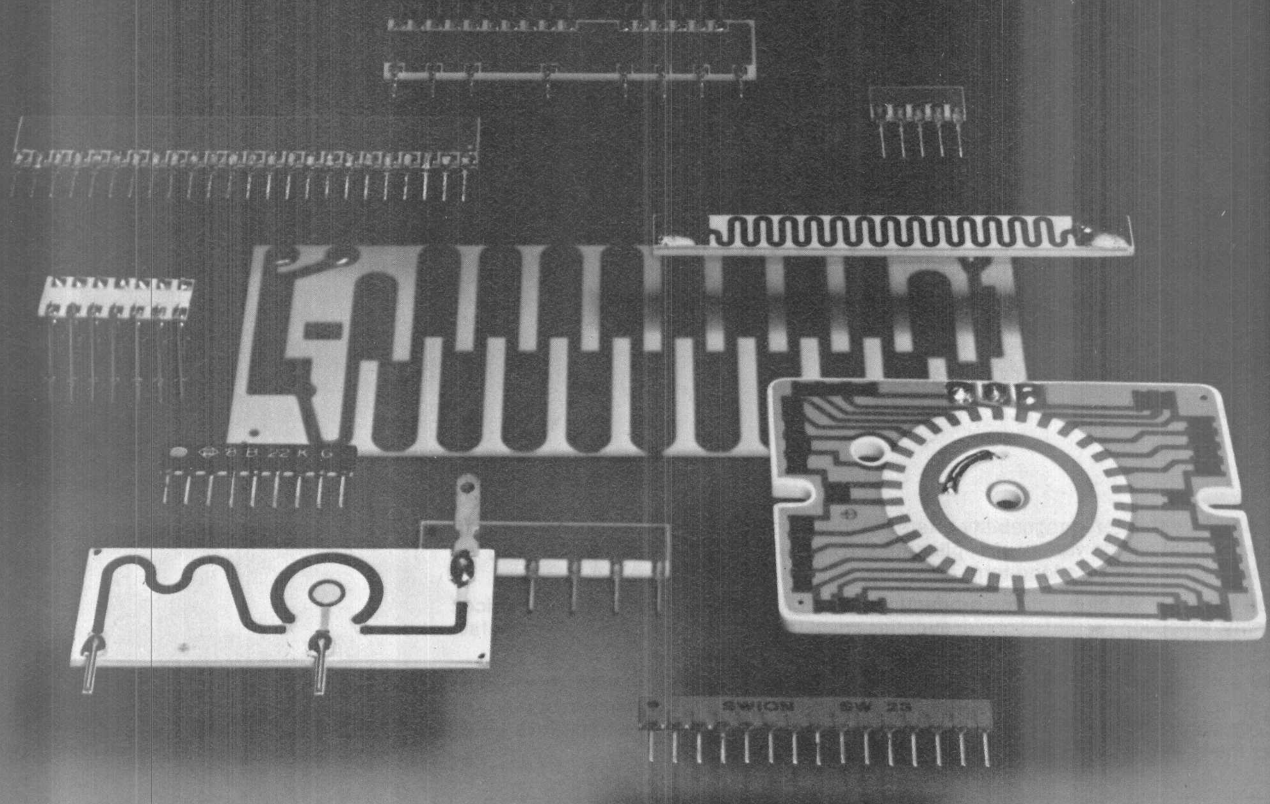
Mauchly had also been exposed to digital computing concepts, primarily through a visit to John V. Atanasoff at Iowa State College during the summer of 1941. Atanasoff did not become well known until years later, when he testified in a patent infringement case involving the original patent of the electronic computing concept held by Eckert and Mauchly. But Atanasoff is now recognized as having contributed to Mauchly's electronic digital computing idea.

In 1942 Mauchly began discussing with members of the Moore School his idea for using vacuum tubes to perform calculations, and the idea came to the attention of Goldstine at the Ballistics Laboratory. After several months of discussions, the Government, on June 5, 1943, signed contract W-670-ORD-4926 with the University of Pennsylvania to develop the proposed Electronic Numerical Integrator and Computer—known as Eniac. Mauchly supervised much of the logical design, while Eckert concentrated on the electronics engineering and Goldstine assured support for the project.

The era of the electronic digital computer was ushered in with the dedication of Eniac on Feb. 15, 1946. Although it was too late to help with the war effort, Eniac's first practical chore was to perform some problems prepared by von Neumann for the then top-secret atomic bomb project at the Los Alamos Laboratory in New Mexico. Later moved to the Aberdeen Proving Ground, Eniac was to continue in operation until October 1955.

Accounts of the day are reminders of how awesome the new computer was: using 18,000 vacuum tubes, the U-shaped Eniac occupied a room 30 by 50 feet, weighed 30 tons, and consumed some 150 kilowatts of power. Operating with a basic clock rate of 100 kHz, it could perform additions in 0.2 ms, while multiplication took about 2.8 ms—some thousand times faster than electromechanical machines of the day.

Instead of binary notation, Eniac used decimal notation and could handle up to 10 decimal digits with decade counters functioning as the accumulators that stored the numbers in the machine. But for all its advances, Eniac had one drawback: it was controlled by a patchboard of wiring. To change a program, the operator had to disconnect wires and plug them into different locations—an operation that could easily take days. In



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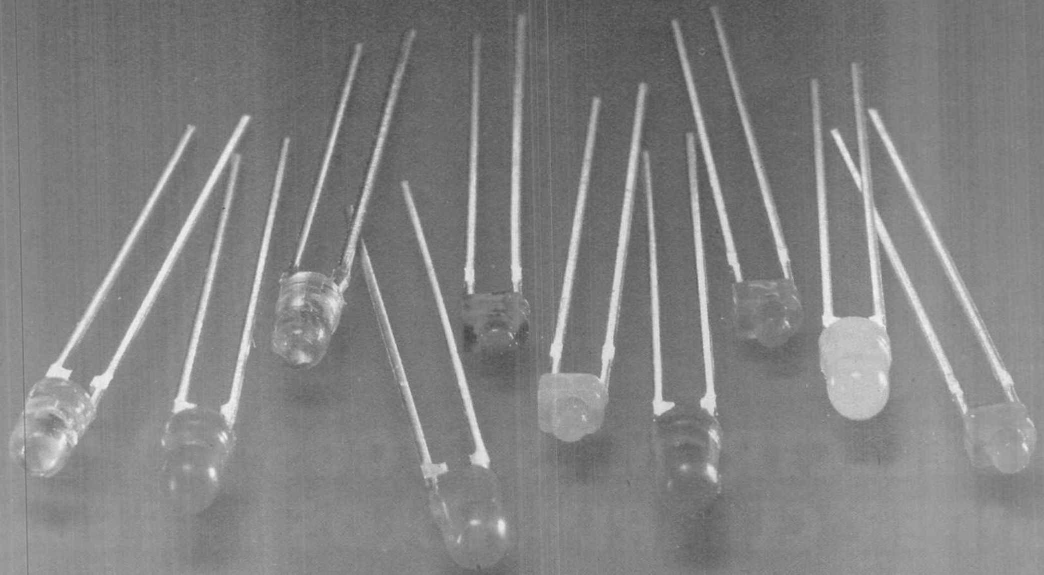

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Ø 3	CQX 25 N CQY 85 N	CQX 42 N CQX 41 N	CQX 26 N CQY 86 N	CQX 27 N CQY 87 N	CQX 46	BPW 42

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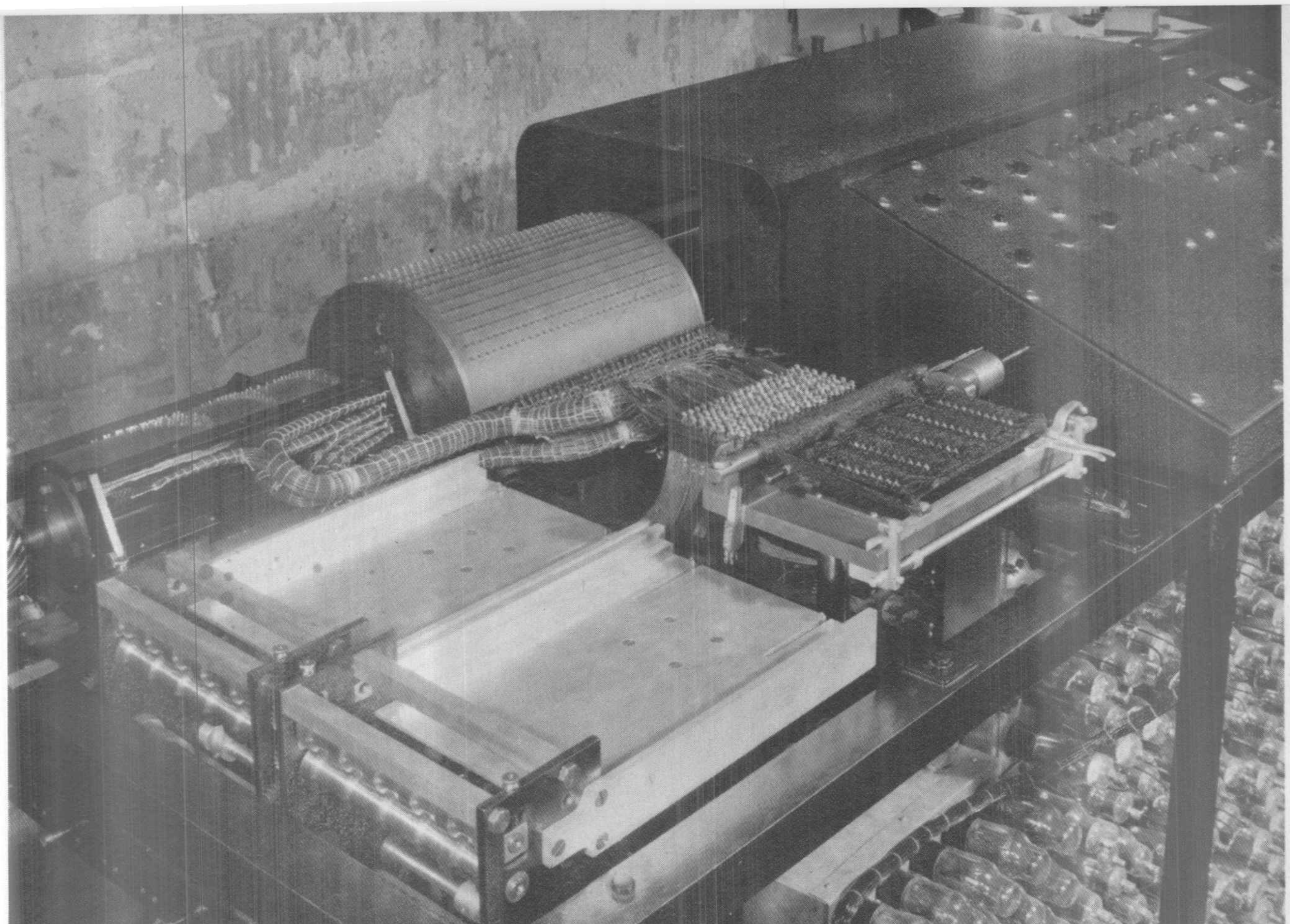


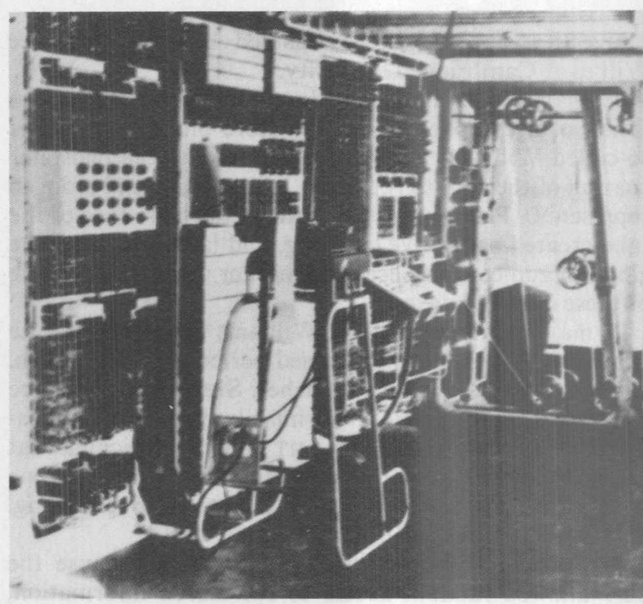
Precursor. This prototype digital computer, one of the earliest to use vacuum tubes as logic elements, was designed and built by John V. Atanasoff at Iowa State College for solving linear algebraic equations. He became involved in a patent dispute with Eckert and Mauchly.

Eckert's recollection, it was almost immediately evident that such a programming technique was so cumbersome that it would cancel out the computer's inherent processing speed. So plans were drawn for a computer that would store the program electronically in the same way that the machine stored data. In August 1946 the Moore School held a series of lectures on its proposal for a computer that would have a memory like this: the Electronic Discrete Variable Computer, or Edvac.

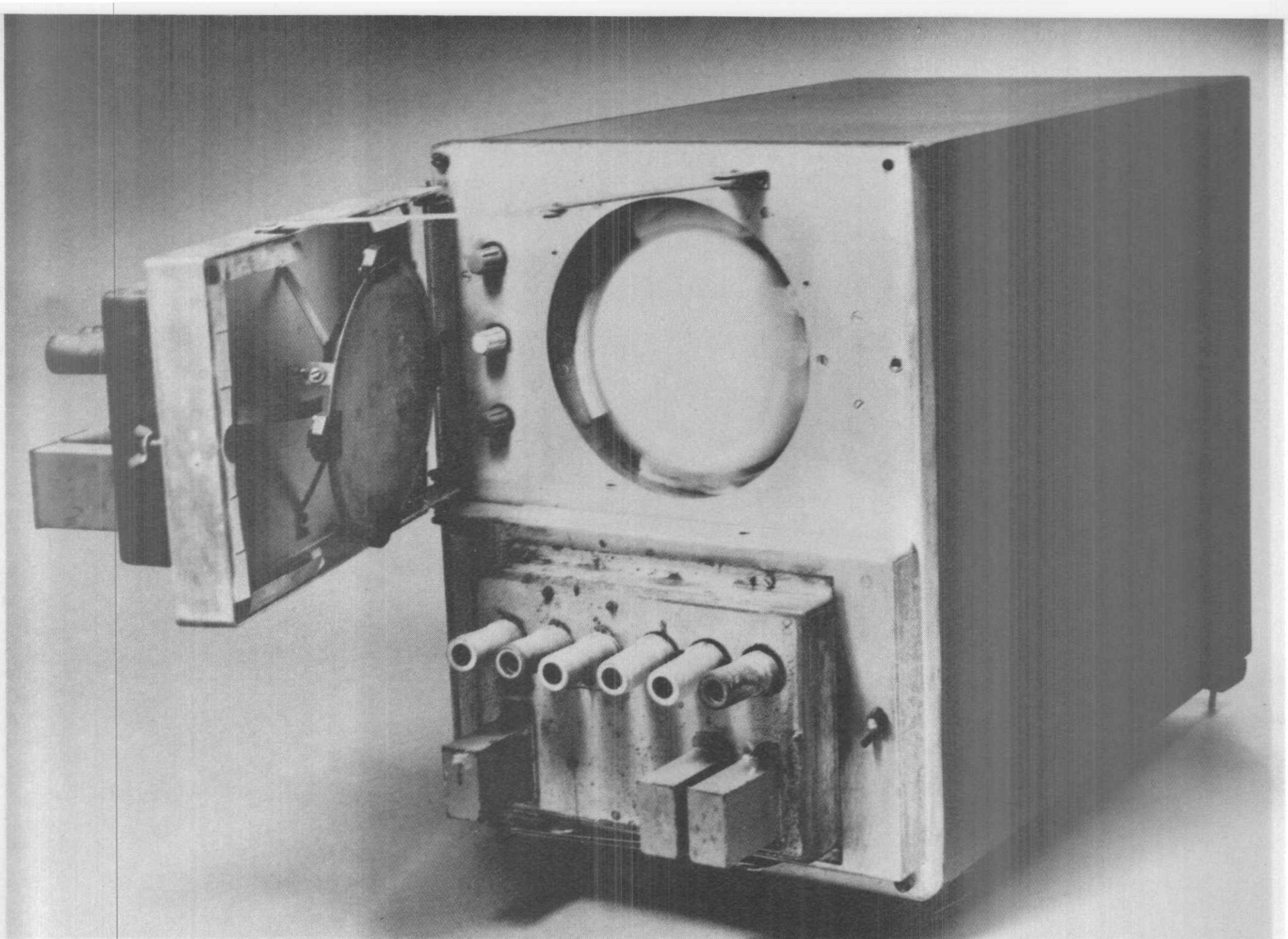
Eckert notes that from these earliest days of computer engineering, "memory controlled the architecture design." The only electronic memory element available as Eniac was being developed was the flip-flop tube circuit—an expensive technique that was reserved for data being processed. But the mercury delay line, a result of radar research associated with the war, was now available and designed into Edvac. The designers noted that if the signals propagated, or delayed, through the mercury were amplified and recirculated, the information could be held in the line indefinitely and could be accessed each time it came around.

The British were already involved in electronic digital techniques, having built Colossus, a 1,500-tube cryptanalysis machine at the government's Bletchley Park Establishment in 1943. The specialized Colossus is thought by some to hold the title of the first electronic digital computer.

With this beachhead in electronic computers, Britain moved to coordinate its developments by establishing a National Mathematical Laboratory in 1945. The laboratory worked with two groups that were to have a major influence on early computing work: one was headed by F. C. Williams, first at the Telecommunications Research Establishment and later at Manchester



British entry. Claimed by some to be the first electronic digital computer, Colossus was built by the government's Bletchley Park Establishment in 1943 for cryptanalysis applications. UK scientists went on to make significant contributions to computer technology.



Breakthrough. The Williams tube, named for its inventor, F. C. Williams, was the first all-electronic memory, essentially a storage tube that utilized capacitive coupling at the tube face to sense data in the form of charges stored on the phosphor coating.

University, and the other was led by Prof. Maurice Wilkes at Cambridge University.

Williams' first significant development was the adaptation of a cathode-ray tube to store bits of data. This so-called Williams tube wrote a dash onto the phosphor coating of the CRT to represent 1 bit of data and a dot to represent 0. Placing a metal plate on the glass face of the tube created capacitive coupling, and later sweeps of the electron gun could be used to sense, or read, the presence of these dots and dashes.

A major advantage of the Williams tube was that the same electron gun could be used periodically to refresh, or regenerate, the dots and dashes. Similar storage-tube developments in the U. S.—primarily by Jay W. Forrester and Andrew Haeff at MIT and J. Rajchman at RCA—used more complex refreshing techniques with one gun for reading and writing and a second for refreshing. They proved to be less practical.

The storage-tube approach was favored because the CRT allowed random access to the stored information, instead of the serial access available in the mercury delay lines. Williams joined Manchester University in December 1946 to perfect the storage tube and at the same time begin development of what was to become the first stored-program computer.

Wilkes, the Cambridge professor, having attended the lectures on Edvac at the Moore School, returned to Britain to start development of the Electronic Delay Storage Automatic Computer, or Edsac. This was in November 1946.

At the heart of Edsac's design were 5-foot-long steel tubes filled with mercury to function as delay lines. Although influenced by Edvac, which was being designed concurrently in the U. S., the Wilkes group finished Edsac two years earlier, in 1949.

An important event in 1946–47 was the emergence of George A. Philbrick's vacuum-tube operational dc amplifier as a commercial product. This high-gain, low-drift unit ushered in the era of the fully electronic analog computer. The initial op amp was produced by George A. Philbrick Researches Inc., which survives today as Teledyne-Philbrick, a producer of solid-state data-conversion equipment.

It was a period of feverish activity in computer research and development. Researchers at the Servomechanisms Laboratory at MIT, which had been developing analog computers to control aircraft simulators for pilot training, realized that electronic digital computing could do the simulator's real-time task faster and more accurately. So in 1947 the laboratory began developing its project Whirlwind, a program that was sponsored initially by the office of Naval Research and later by the U. S. Air Force.

Inevitably the commercial world took a growing interest in the new computers. In 1947 the two pioneers from the Moore School left to form the Eckert & Mauchly Computer Corp.—the first of what was to become an entire industry of companies dedicated to the design of electronic computers.

World War II halted the sale of radios to the civilian market. But manufacturers turned out sets for the military in record numbers. From walkie-talkie and back-

pack sets in the front lines to table models and complete stations elsewhere, radio often was the fine line between victory and defeat. Variations on the state of the art sufficed for basic communications. The developmental work was secret, of course.

One effect of the war was that it delayed the natural development of frequency-modulation radio. The FCC had authorized commercial fm broadcasting on Jan. 1, 1941, assigning it to 40 channels in the 42-to-50-MHz band. That year the industry sold more than 350,000 fm receivers out of 13 million radios in all that went to consumers. Radio manufacturers and broadcasters seemed to assume that fm, because it offered better sound and noise-free reception, would simply replace amplitude-modulation broadcasting, much the way sound films had replaced silent. A November 1943 article in *Electronics*, looking ahead to postwar fm, said:

"The present system is completely commercial from a technical point of view, although it could probably be improved by granting permission to increase the power of fm transmitters so that improved signal strength would expand the proposed service areas."

The article concluded with perhaps a touch of naive optimism: "The industry had a particularly brilliant opportunity to place broadcasting on a quality high-fidelity basis, and many will make the sincere effort toward this goal."

Seven months later, in June 1944, a Zenith Radio Corp. executive, J. E. Brown, sketched a glowing picture of fm's postwar future, estimating that 28 million homes would be served by fm stations and that two thirds of these would buy an fm radio, or 18.6 million sets. He also pointed out something that must have been giving a-m station licensees anxious moments.

"The service area of a 250-W fm broadcasting station is more than four times that of a 250-W, 1,000-kHz a-m broadcasting station at night," Brown observed. He argued that the public was interested in fm's higher fidelity as a logical, natural advance in radio progress and that "unless the FCC changes broadcasting allocations, a-m can never offer the frequency response of fm."

In fact, broadcasting allocations were being reconsidered. In 1943 the FCC had asked the Institute of Radio Engineers and the electronics industry to develop plans for postwar electronic activities. The industry formed the Radio Technical Planning Board, with panels on a-m, fm, and television, while the Government formed the Interdepartment Radio Advisory Committee. In late 1944, the two groups proposed assignments covering the spectrum from 10 kHz to 30,000 MHz.

On June 27, 1945, the FCC moved the fm band from 42 to 50 MHz, which was assigned to nongovernmental fixed and mobile radiocommunications and to television channel 1. The fm band became 88 to 106 MHz, with 100 channels. The commission also cut the permissible power of fm transmitters to one tenth of the a-m level, limiting coverage of each station to a single city.

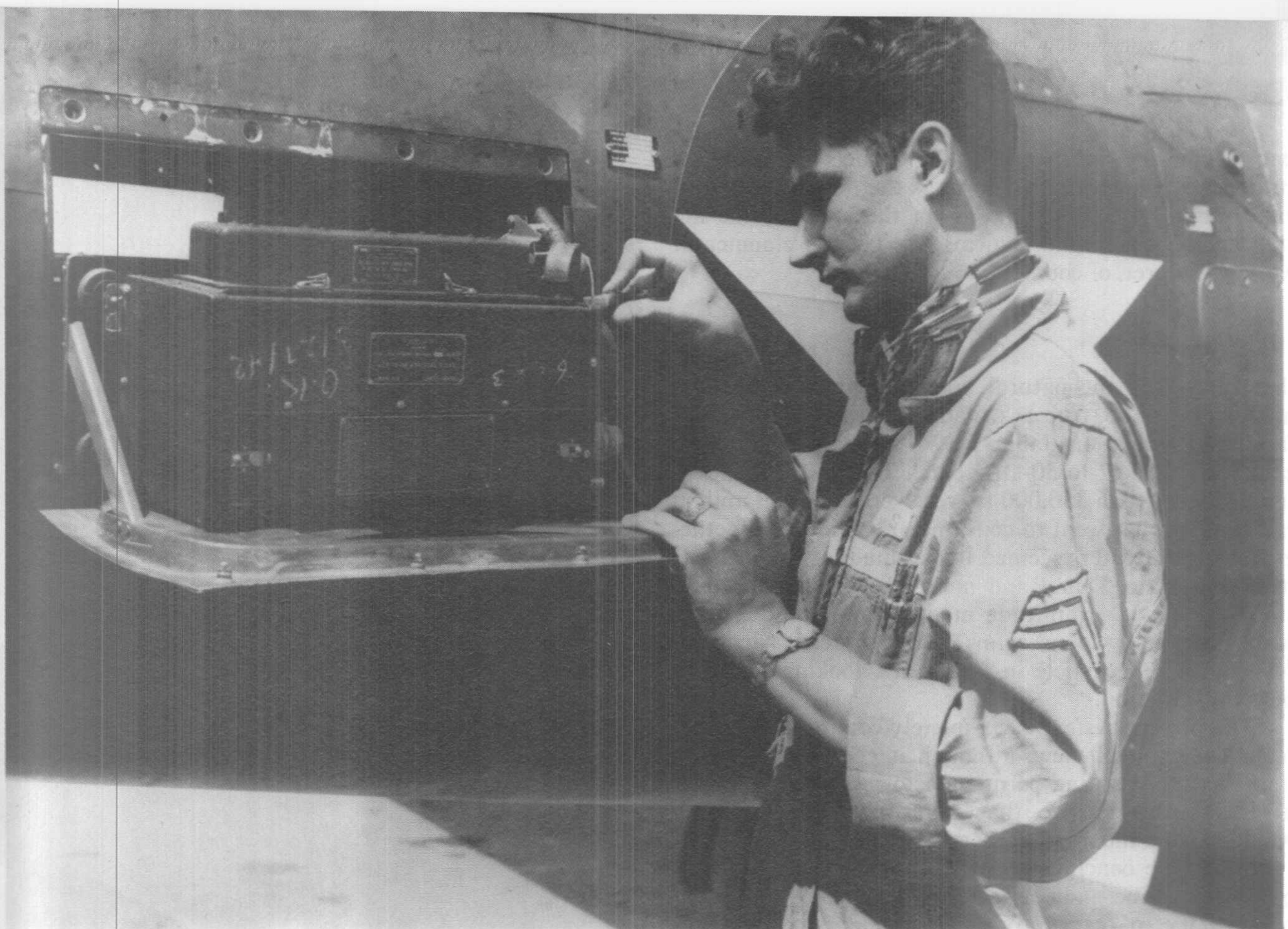
The shift affected the 46 licensed fm stations and 7 stations operating under construction permits. It meant that all 248 fm station license applications had to be withdrawn, recomputed, and resubmitted. It also made all existing fm receivers obsolete, a point that was raised at the FCC hearings and dismissed on the ground that most fm radios could also receive a-m. A $10 converter was demonstrated to the commission that would make existing fm receivers capable of tuning to the higher frequencies.

Once the allocations had been set and the war ended, engineers began reporting technological improvements. In October 1945, for example, William Maron, a senior radio engineer with the North American Philips Co., pointed out that most existing fm receivers drifted badly until they had warmed up and even then required occasional retuning. He suggested quartz crystals in the local oscillator as the most economical way to obtain high tuning accuracy and stability.

A year later a Zenith engineer suggested that the complete home radio receiver must have standard broadcast and shortware a-m bands, two fm bands, and automatic tuning, and he described a receiver that economically included all five.

In July 1947, *Electronics* described in detail a Crosley

Whirlwind. At MIT, researchers turned to digital computing techniques to achieve real-time simulation. Project Whirlwind was set up in 1947. Shown here with Whirlwind I is memory pioneer Jay W. Forrester (left), Patrick Youtz (center), and Stephen H. Dodd.



Compact. The war years accelerated developments in radio communication gear, and here too ruggedization and reduction in size became essential, as exemplified by this Army Air Force uhf/vhf command set built by Western Electric, to be installed in fighter aircraft.

Wartime pitch. Sales of civilian radio sets came to a halt during the war, with the industry rallying to the cause and turning out millions of military sets, including the Handy-Talkie and the later Walkie-Talkie two-way portable radio for tactical communications.

chassis: an eight-tube double superheterodyne that covered the broadcast band; the shortwave band, including the 25- and 31-meter regions; and the fm band. The design offered high sensitivity and low noise on all bands. It was simple enough for a manufacturer to build on a high-speed assembly line and stable enough for the consumer to tune it easily.

Television hibernated, for the most part, while the war raged, though experimentation continued in low key. On June 24, 1940, a coaxial cable was used for the first time for TV transmission and reception between New York and Philadelphia, and on Aug. 27 of that year the first experimental color telecast was made from a CBS transmitter in New York. In 1941 two stations, WNBT and WCBW in New York, became the first TV transmitters commercially licensed to go on the air. But there was nothing like normal programming today.

In March 1942 *Electronics* reported that TV was being used to help train air raid wardens in New York. Some 18,000 wardens were reported being instructed via a TV hookup three days a week. It was one of the rare times that the medium became part of the war effort.

Instead of developing commercial television tubes, electronics manufacturers improved the cathode-ray tube for war service. Radar, sonar, loran, and some of the radio direction finders used by the armed forces had CRTs for readouts. Double-layer, dark-trace, and exponential screens were produced, as well as multiple-gun and projection CRTs, and improvements were made in electrostatically and magnetically focused tubes.

With this background to build on, RCA was able to introduce the image orthicon in 1945, a new television camera tube invented by RCA researchers Albert Rose, Paul K. Weimer, and Harold B. Law. It replaced the original iconoscope, which had shortcomings in picking up pictures clearly, especially in dim light. Now television was ready to grow as an industry.

The growth started in 1946, with six commercial stations telecasting to a few thousand receiving sets in the United States. It continued at a giddy speed until, barely two decades later, more than 560 stations were telecasting to 56 million sets. Along the way, color television became the dominant medium, but not until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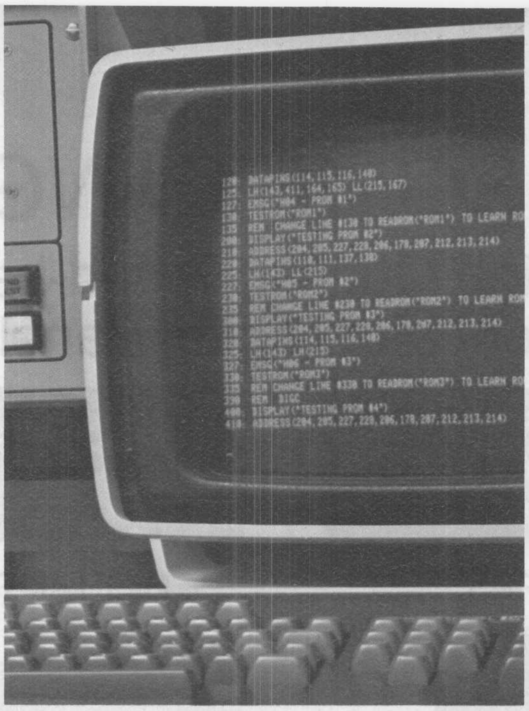

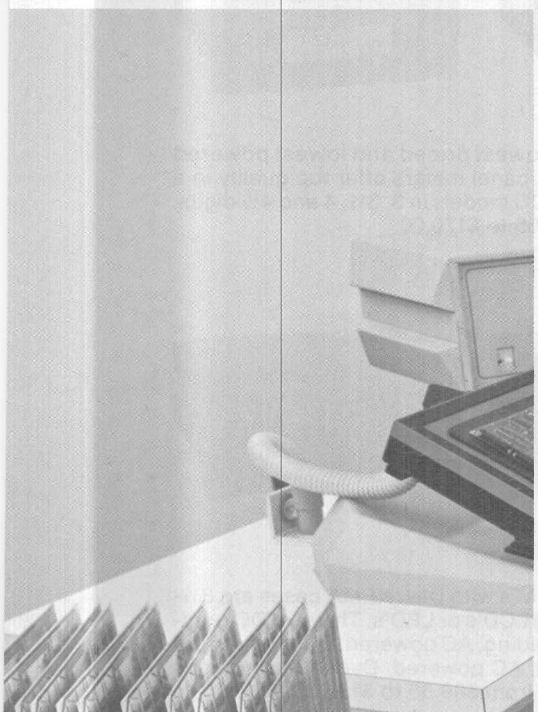

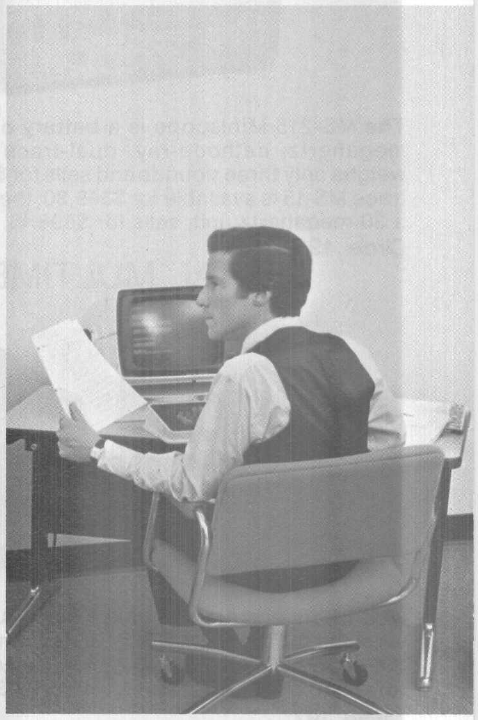


FAIRCHILD

Lighten up. The superior light sensitivity of the image orthicon pickup tube over the iconoscope helped television broadcasting take a significant step forward. Shown here are the inventors, RCA scientists Albert Rose, Paul K. Weimer, and Harold B. Law.

the 1960s. Actually the Federal Communications Commission had authorized commercial TV broadcasting to commence on July 1, 1941, shortly before the commission adopted the standards put forth by the National Television System Committee. RCA had demonstrated a home TV receiver in January 1941, anticipating that these standards would go into effect.

They called for a 6-MHz channel, separation of 4.5 MHz between picture and sound carriers (the sound being 0.25 MHz below the upper edge of the channel), and a line count of 525 per frame. Transmission was to be at 30 frames per second. Field tests had revealed that there were problems with sending the video portion of the signal by frequency modulation—there was distortion under multipath conditions—and accordingly the FCC had ordered a-m for the video transmission and fm for the audio.

The standards had been drafted with black-and-white television in mind. Color TV had not yet approached the point of commercial feasibility. Yet so durable were these basic specifications that they remain virtually unchanged to this day.

Even as black-and-white TV was gaining a foothold, two basic approaches to achieving color TV emerged: the field-sequential method and the line-sequential. The first employed frame-by-frame transmission of signals corresponding to each of the three primary colors of light—red, blue, green. The second approach transmitted the hues simultaneously. From the primary colors, any color in the spectrum could be synthesized.

Researchers soon realized that the field-sequential method would require rapid scanning of the scene to avoid color flicker in the received picture; this would not be compatible with black-and-white TV. But the line-sequential method appeared to be more complex, requiring more than one picture carrier and perhaps even greater bandwidth than black-and-white needed.

It was a formidable challenge, because, as Worthington Miner, manager of television for CBS in 1943, put it: "Television without color must walk with a crutch."

Miner argued that color television demanded larger bandwidth and that this, in turn, implied transfer to higher frequencies. "Television under present standards is not good enough," he said. "It can be good enough—and very quickly—if we do not wantonly dissipate, but use intelligently, the advantages of the present hiatus."

CBS went on the offensive with an electromechanical system developed by Peter C. Goldmark, who had been credited with the first broadcast transmission and reception of a color TV picture in 1940. This was shortly after RCA had demonstrated an all-electronic system for color TV at its plant in Camden, N. J.

Goldmark's system was a field-sequential one (343 lines, 120 frames per second). It used a spinning disk with red, green, and blue filters to scan the scene to be transmitted. A second filter disk, at the receiver, was made to spin in synchronism with the transmitter disk. This second disk served the function of colored phosphors in modern color TV by re-creating the color in the


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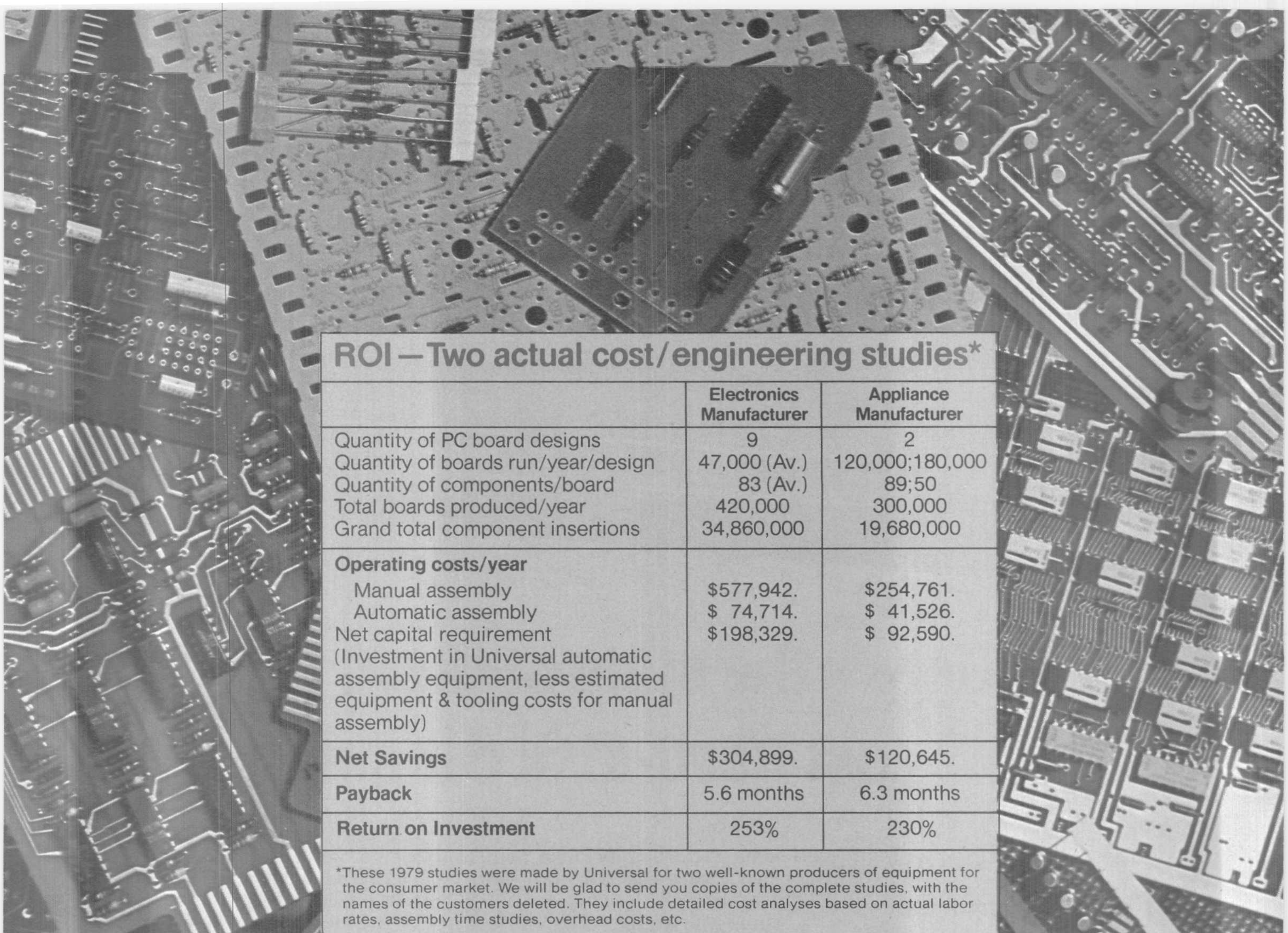

ROI—Two actual cost/engineering studies*

	Electronics Manufacturer	Appliance Manufacturer
Quantity of PC board designs	9	2
Quantity of boards run/year/design	47,000 (Av.)	120,000;180,000
Quantity of components/board	83 (Av.)	89;50
Total boards produced/year	420,000	300,000
Grand total component insertions	34,860,000	19,680,000
Operating costs/year		
Manual assembly	$577,942.	$254,761.
Automatic assembly	$ 74,714.	$ 41,526.
Net capital requirement (Investment in Universal automatic assembly equipment, less estimated equipment & tooling costs for manual assembly)	$198,329.	$ 92,590.
Net Savings	$304,899.	$120,645.
Payback	5.6 months	6.3 months
Return on Investment	253%	230%

*These 1979 studies were made by Universal for two well-known producers of equipment for the consumer market. We will be glad to send you copies of the complete studies, with the names of the customers deleted. They include detailed cost analyses based on actual labor rates, assembly time studies, overhead costs, etc.

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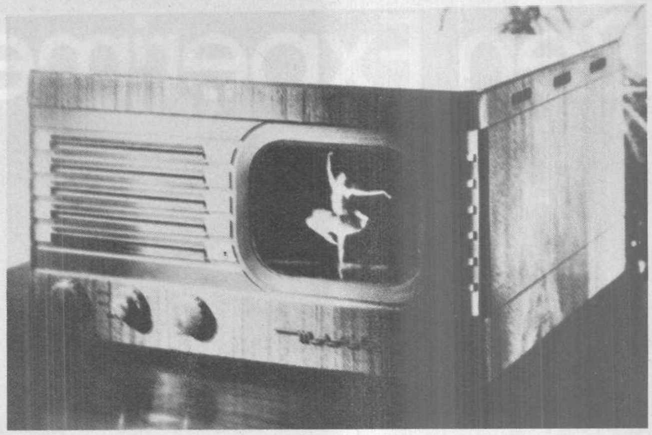
monochrome system.

So in December 1946 CBS proposed separate channels for TV color and black-and-white systems. The FCC rejected this idea in March 1947, and the struggle for a TV color standard continued.

RCA pressed work on a system that was to develop into its so-called dot-sequential arrangement, which would be compatible with black-and-white TV. Dots of the primary colors were formed in rapid succession along each scanning line, and the colors were transmitted simultaneously with black and white by use of the monochrome scanning standards of 525 lines per frame and 60 fields (30 frames) per second. With an external adapter, the black-and-white receiver was tuned to only one component of this signal—that corresponding to the green primary image.

After some waffling by the FCC in the early 1950s, the commission settled for the RCA-compatible system.



Early model. Regular commercial television broadcasting got under way in 1946 with six stations telecasting to a few thousand sets. This Motorola set introduced in 1947 was designed to sell for under $200. Color did not become significant until the 1960s.

Meanwhile the phonograph industry was poised for dramatic advances that were to take this instrument of entertainment a long way from its prewar days of unwieldy 78 rpm records and heavy pickups with steel needles. Since the 1930s engineers had been seeking three things: higher fidelity, longer-playing records, and more realistic sound. Electromechanical pickups had been introduced in the late 1920s, together with electronic volume and tone controls. Researchers in Britain and at Bell Telephone Laboratories almost simultaneously had demonstrated stereophonic reproduction in the early 1930s. But while engineers pushed for higher fidelity, their employers felt that the public would not pay for it.

The industry had recognized that a lightweight pickup diminished record wear and improved performance, and by coupling the stylus to a Bimorph Rochelle salt transducer element, manufacturers had placed on the market in the late 1930s a number of crystal pickups capable of tracking at one to two ounces.

In April 1941, *Electronics* reported a method of recording stereo on a conventional record: two bands, one on the outer edge of the record and one on the inner, recorded by two cutter heads, with the music reproduced by two pickups. Two years later the magazine suggested a circuit by which an engineer could divide an audio signal into high and low frequencies to give the illusion of stereo.

To answer the demand for longer playing time, engineers developed better ways to change records. A February 1942 article in *Electronics* had dismissed the long-playing tape machines and 33⅓ rpm records used by radio stations as too expensive for the mass home market. Mechanical record changers were able to cycle in 8 seconds, and there were three that played both sides. One by RCA used a turntable about the size of the record label and two pickups on the tone arm. Record changers by Garrard and Capehart played one side, then picked up the record, turned it over, and played the other.

In November 1945 Paul W. Klipsch described the design and construction of a crossover network for feeding a low- and a high-frequency horn from a single amplifier. It used low-cost components yet gave a high-fidelity response, flat within 2 decibels from 30 to 10,000 hertz. A year later London Records announced a phonograph with a frequency response of 50 to 14,000 Hz, plus or minus 1 dB.

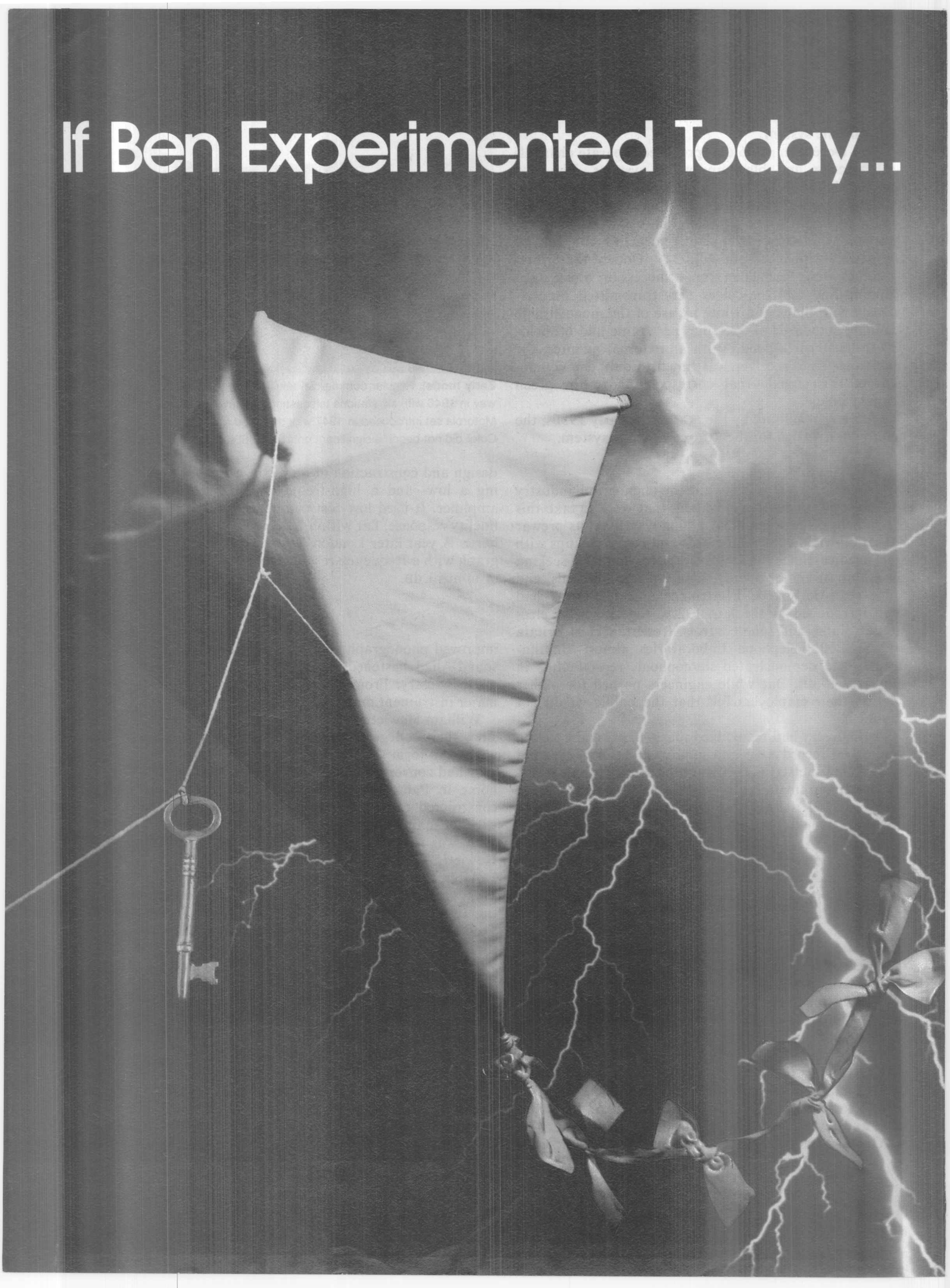
A development that ultimately improved phonograph reception radically—stereophonic sound—had hastened the growth of the infant instrument industry. From stereophonic sound, there arose a major instrument manufacturer—Hewlett-Packard.

William Hewlett and David Packard had been friends since their college days at Stanford University and had wanted to form their own electronics company. By 1938 they had converted the small garage behind the Packard home in Palo Alto, Calif., into a workshop and had constructed a resistance-tuned audio oscillator. The unit, with its enamel finish baked on in the Packards' kitchen oven, was named the model 200A because, according to Hewlett, "the number sounded big."

After the 200A had been displayed in 1938 at the West Coast meeting of the Institute of Radio Engineers, the two designers received a letter from Walt Disney Studios: could they produce a slightly different oscillator that would cover a different frequency range? Disney wanted it for his musical cartoon extravaganza "Fantasia," which was to have a new process in sound recording on film—stereophonic sound. The process called for three sound tracks, amplitude-compressed to fit on the film, plus a fourth decompression track.

With an order for eight oscillators in hand, Hewlett and Packard founded their company on Jan. 1, 1939, and built the model 200B.

During the war the instrument industry had helped out quietly. There had been, for example, a new weapon that had threatened Allied shipping: the magnetic mine. It exploded when it detected the magnetic presence of a large body of metal floating directly above. Therefore,


If Ben Experimented Today...

Innovator. Peter C. Goldmark's field-sequential color TV system for CBS, which used a spinning color wheel (left), ultimately lost out to RCA's dot-sequential system. A major success was his long-playing record, which made the 78-rpm disk obsolete.

to protect ships, a method of demagnetizing them was invented. By wrapping several turns of wire around the hull of a ship and electrifying it, one could "degauss" the effect of the earth's magnetic field on the ship.

The General Electric Co. developed a special form of fluxmeter to measure the effectiveness of this degaussing. The meters were connected to coils on the bottom of a harbor, and as a test ship passed over them, the measurement was made. This same principle was applied to safeguarding harbors: by noting fluxmeter deflections and comparing them to the known movements of Allied shipping, defenders could detect the presence of an enemy submarine.

There were comparable instrumentation contributions to wartime computing. A new device that was to have great impact after the war was the four-tube decade counter. Developed by John T. Potter of the Potter Instrument Co., the simple counter used a 1-2-4-8 binary progression and could be ganged with other such units for high-order counting. It was described by Potter in the June 1944 issue of *Electronics*.

With manpower shortages at home, manufacturers came up with a wide variety of equipment to permit testing of components by fewer people of lower skills. The February 1943 issue of *Electronics* notes one such effort, a forerunner of automated assembly-line testing.

Dana Griffin and Newton Smalley of Communications Measurement Laboratories described it as the Rotobridge. The tester would automatically and sequentially check the capacitors, inductors, and resistors of a production unit against those of a known good unit. In simple go/no-go fashion, it indicated the presence of a bad element. The $850 tester could perform both resistance and reactance tests on 120 circuits in 4 minutes.

In addition, the war was an intense training ground for engineers who, like Hewlett and Packard, formed their own companies. Among them was Howard Vollum, a graduate of Reed College in Portland, Ore., where he built his first oscilloscope. Vollum had been drafted in 1940 and sent to England, where he trained on high-resolution radar development. He returned to the Evans Signal Laboratory at Belmar, N. J., a few days before D-Day, where he worked on radars to determine enemy ground positions. While with the laboratory, Vollum encountered Hewlett, by then a fellow serviceman, who is said to have written to Packard telling him to hire Vollum after the war.

That job offer never materialized. Instead, after Vollum left the military and returned to Portland, he, Jack Murdock, and other associates founded Tektronix Inc. on Jan. 2, 1946.

The first Tektronix factory was the second floor of an electrical appliance store, which was also run by the company founders and helped to supply them with seed money. After a year and a half of steady effort, Tektronix' first product—the 511 oscilloscope—was ready for the marketplace.

The 511 incorporated many advances that had been developed for radar, including automatic triggering. Calibrated to an accuracy of $\pm 5\%$, the 10-MHz scope weighed 65 lb and sold for about $700—roughly a third the cost and weight of its principal competition.

Another war veteran with a dream was Joseph Keithley. In a back-alley store in Cleveland, he began the Keithley Instrument Co. on his own.

His first product was the "Phantom Repeater," a high-impedance-input amplifier that put little drain on the circuits used in conjunction with it. While this device

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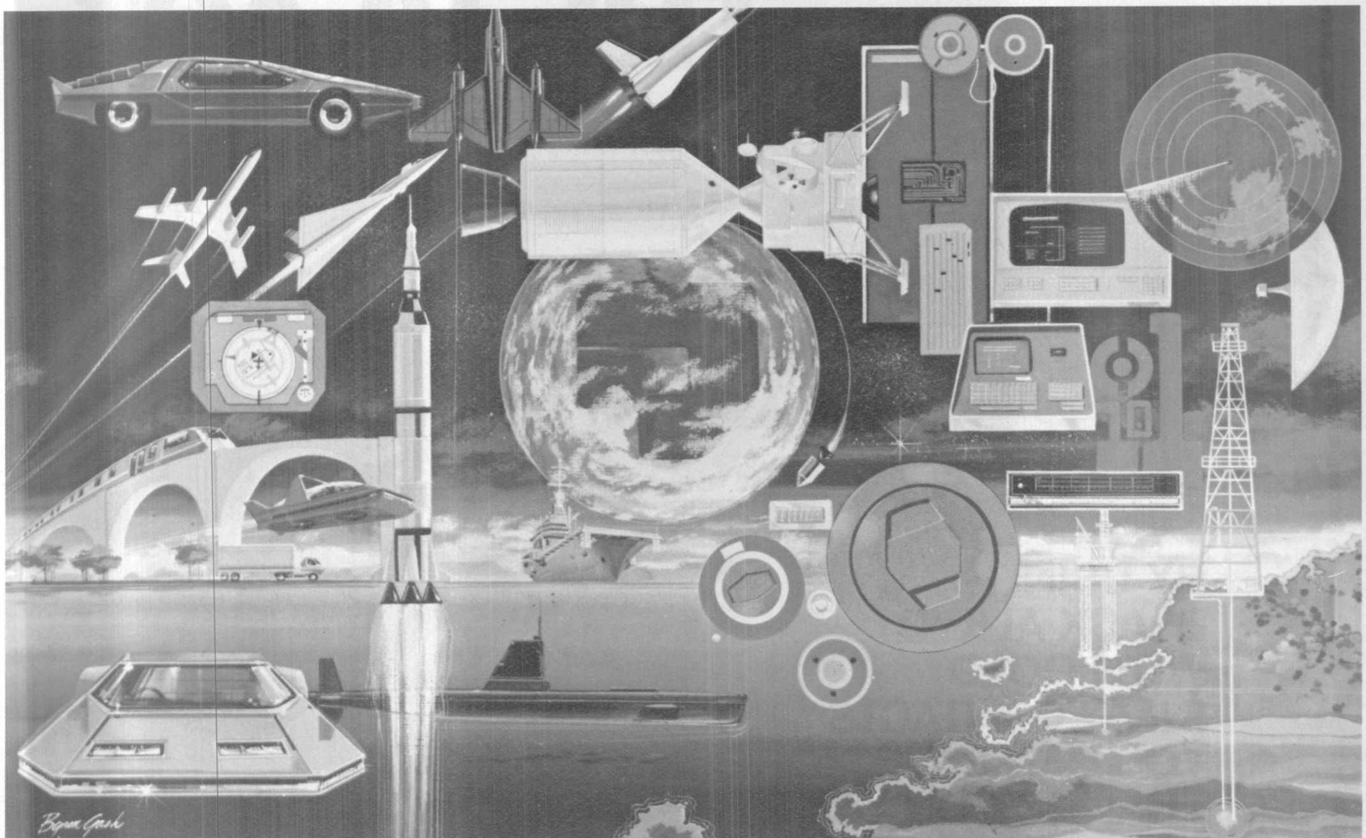

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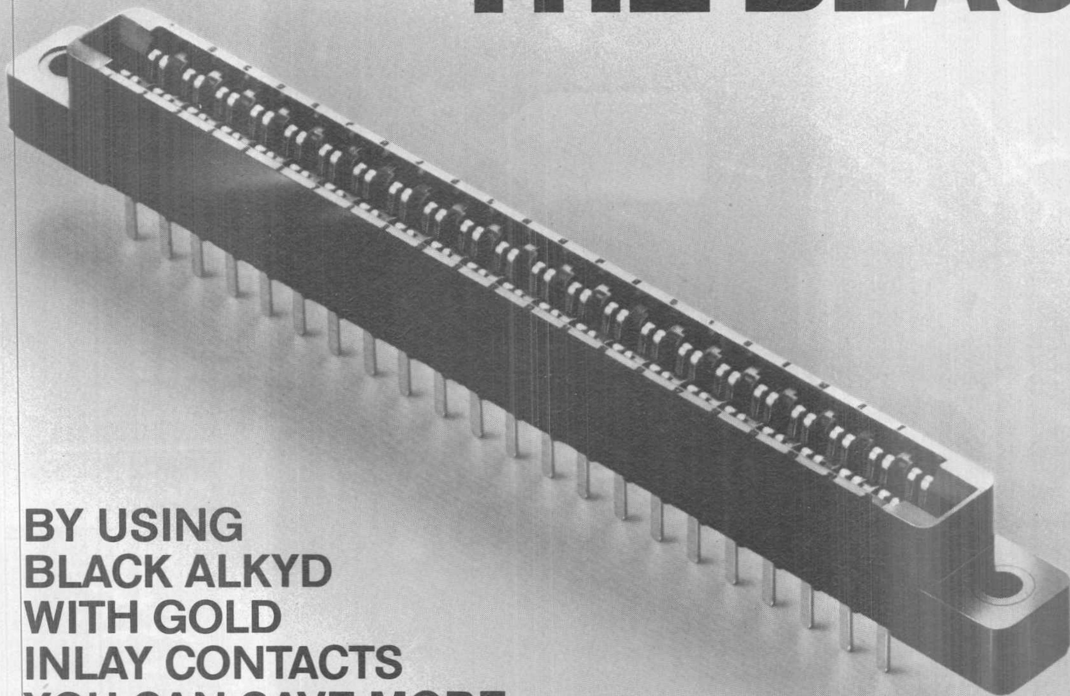

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was not the great success he had hoped for, it supplied enough capital for him to develop his first electronic electrometer, which fully launched the company.

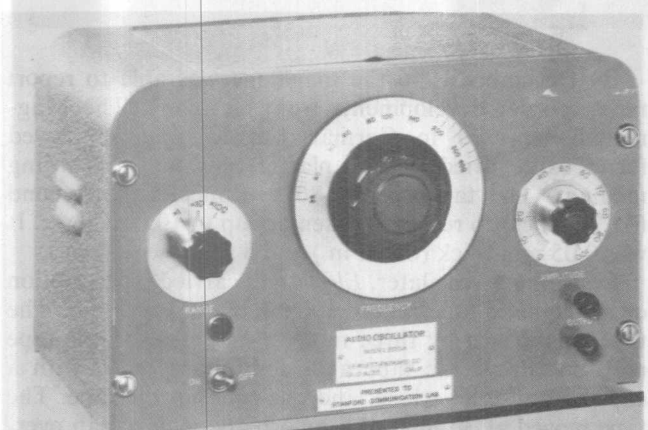
In the realm of instrumentation theory, discoveries were recorded unostentatiously in the literature. The June 1940 issue of *Electronics* contained a cover article entitled "Panoramic Reception." Developed by Marcel Wallace, an independent consultant, the technique displayed the output of a frequency-swept superheterodyne receiver on a sweep-synchronized oscilloscope. Wallace initially saw the application of this signal-strength-to-frequency display as valuable to radio navigation, with variance in signal strength providing a measure of position. But another application of the technique is probably more familiar to engineers today.

In an August 1941 article in *Electronics*, S. F. Carlisle Jr. and A. B. Mundel of the Sonotone Corp. described the application of the principle to test circuitry, providing a logarithmic display of its response. Thus spectrum analysis became an important new tool in engineering evaluation.

As broadcasters attempted to reach wider audiences, the dynamic characteristics of vacuum tubes—their ability to withstand higher voltages and currents when the duty cycle was low—were more closely studied. In the March 1941 issue of *Electronics*, Jacob Millman and Sidney Moskowitz of the City College of New York described a method of tracing tube characteristics on a CRT. The technique has proved so satisfactory that it is still used today for tracing the characteristics of solid-state diodes and transistors.

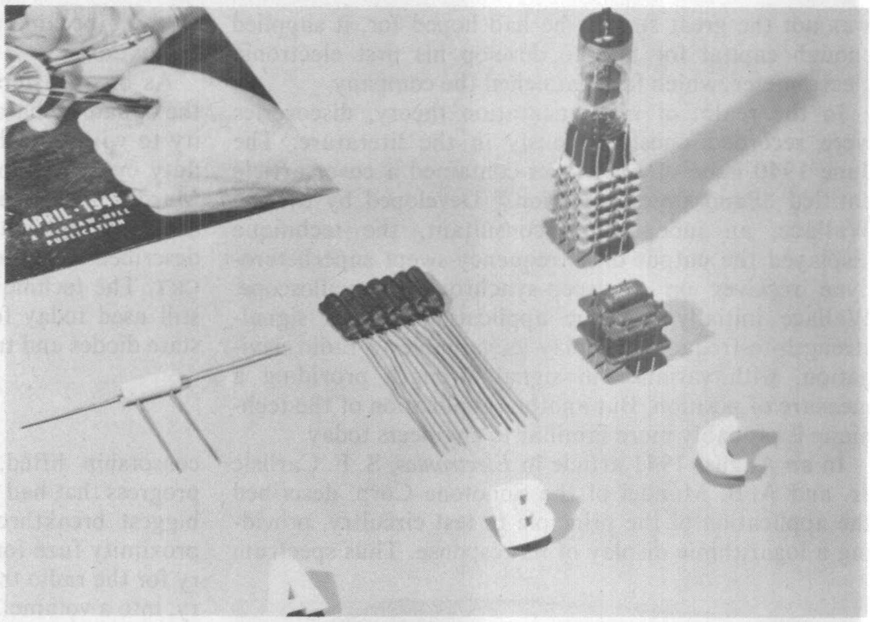
With the veil of wartime censorship lifted, details of some of the electronics progress that had been made began to appear. One of the biggest breakthroughs was in the development of the proximity fuze for mortar shells. To squeeze the circuitry for the radio transmitter-receiver, plus control circuitry, into a volume 3 inches in diameter by 6 inches long, a new method of interconnection was invented: thick-film hybrid technology.

The developers of the fuze—the National Bureau of Standards in cooperation with the Centralab division of Globe Union in Milwaukee—used plates of steatite as substrates. Thick-film silver conductors and carbon resistors were alternately screened and fired onto the substrates. Then small disk ceramic capacitors and subminiature tubes were attached to the substrates, in a



Little acorn. This resistance-tuned oscillator, the 200A, was designed and built by Bill Hewlett and David Packard in their garage. On the strength of an order for eight from Walt Disney Studios, they formed Hewlett-Packard Company in 1939.

In the beginning. Tektronix was one of several firms founded by veterans returning with know-how gained in the services. Tek's Howard Vollum joined Jack Murdock and others to form the company in 1946. Shown here in 1948 is the production line in Tektronix' first building.



Progenitors. Out of proximity-fuze technology came these early attempts at modular circuit design, which ultimately led to printed circuits and hybrid devices. Shown left to right are a tubular capacitor with standard resistor inserted in tube, a phenolic panel bearing etched circuits and leadless passive components, and a stacked plate module dubbed Tinkertoy.

technique that was first described in *Electronics* in April 1946 in an article by C. Brunetti and A. S. Khouri. Centralab produced several million of these devices and went on to apply thick-film technology in the postwar years. The circuits were called printed circuits rather than hybrids, as they are known today.

In 1946 there was also the first mention in *Electronics* of germanium diodes. Writing in the February issue, E. Cornelius of Sylvania described a more refined version of the device used in wartime radar equipment.

By 1947 different forms of printed wiring were starting to appear. A news item in *Electronics* in June that year mentioned that the Franklin Airloop Co. was making radio antenna coils out of stamped wire.

In England in the same year a machine-made radio being produced by John Sargrove Ltd. was using a crude form of the printed circuit. Plastic panels with preformed depressions and holes were fed automatically into electronically controlled machines, where they were successively sand-blasted and sprayed with zinc. Moving through the machine on a conveyor belt, the panels were then milled, so that zinc remaining only in the depressions formed wiring, inductances, and capacitances. Resistors were added by the spraying on of graphite. Finally tube and filter capacitor sockets and hardware were automatically installed.

Another device that was on the verge of becoming a consumer product in 1947 was the tape recorder. As early as 1932, *Electronics* had reported an Austrian tape machine. It used film on glossy printed paper that moved past a light source and a light-sensitive device—sort of a movie soundtrack without the picture. In May 1944 an engineer from the National Bureau of Standards discussed a special steel-alloy continuous tape, a machine with two recording heads, placed on opposite sides of the tape, and two erase heads. The tape was approximately 0.003 in. thick and ⅛ in. wide, and it moved past the heads at approximately 5 ft/s.

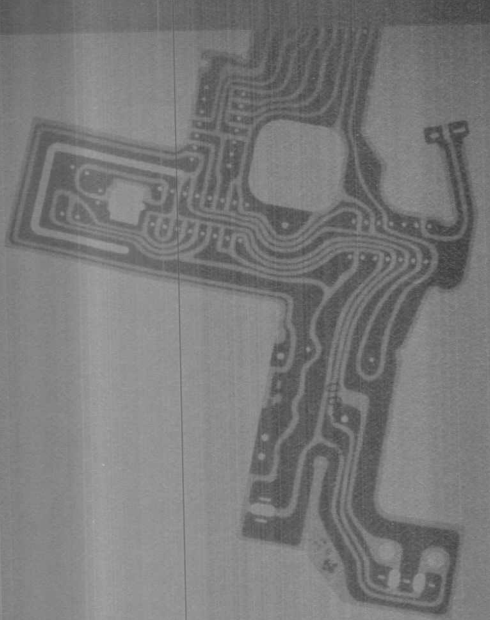
By December 1946 the magazine was able to report tape-recorder developments from Germany. The Magnetophone, used in German broadcasting, employed ferric oxide dried onto a plastic tape as a recording medium. The tape ran at 80 centimeters per second (31.2 inches) to record frequencies up to 10,000 hertz. It was 0.05 mm thick (0.002 in.) and 5 mm wide (⅕ in.).

Less than a year later, *Electronics* carried a description of a magnetic-tape recorder for movies and radio. The tape was driven by three motors: one released the tape reel, one drove the tape at a continuous speed with a capstan and idler wheel, and one took up the tape. The tape moved at 30 in./s and reportedly achieved an overall response flat within 4 decibels from 32 to 9,600 Hz.

There was another development during the war years that eventually became important to consumers. In July 1944, the editors of *Electronics* said: "The possibility of using electronic heat as a domestic cooking medium has often been considered, but the economic aspect is the real drawback to its immediate utilization in the home. The cost is prohibitive because the power tubes require an expensive high-voltage power pack."

By 1947, however, the magazine was describing industrial uses of microwave heat—for drying fabrics, curing rubber, preheating plastics—and it speculated on the possibility of cooking frozen foods. In August 1947, General Electric announced an electronic oven that could heat precooked frozen meals. A commercial unit, it heated a packet for about 75 seconds, raising the temperature to about 160°. The power required was the same as for a domestic electric range.

Perhaps the most far-reaching portent of the time, however, was in the magazine *Wireless World*. In a 1946 issue, Arthur C. Clarke, the British science-fiction writer, proposed a worldwide system of communications based on use of an earth satellite as a great amplifier in space. The satellite in his proposal appeared stationary, in what is now known as geosynchronous orbit.



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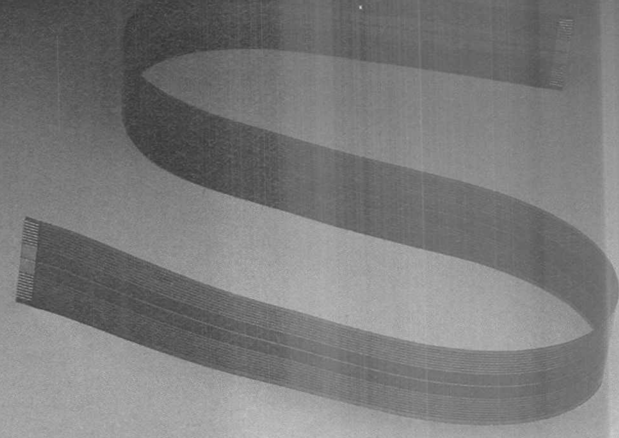

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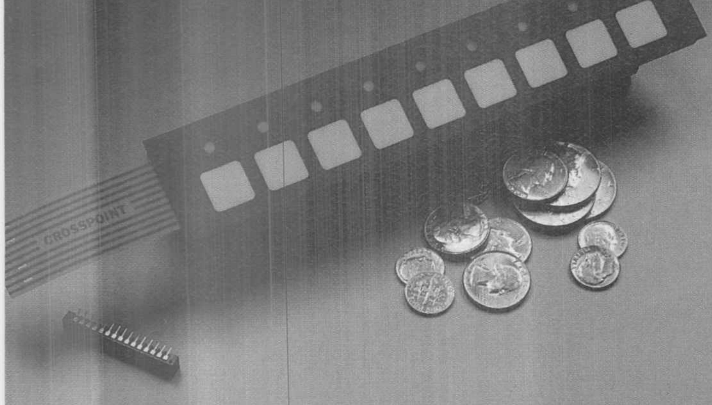

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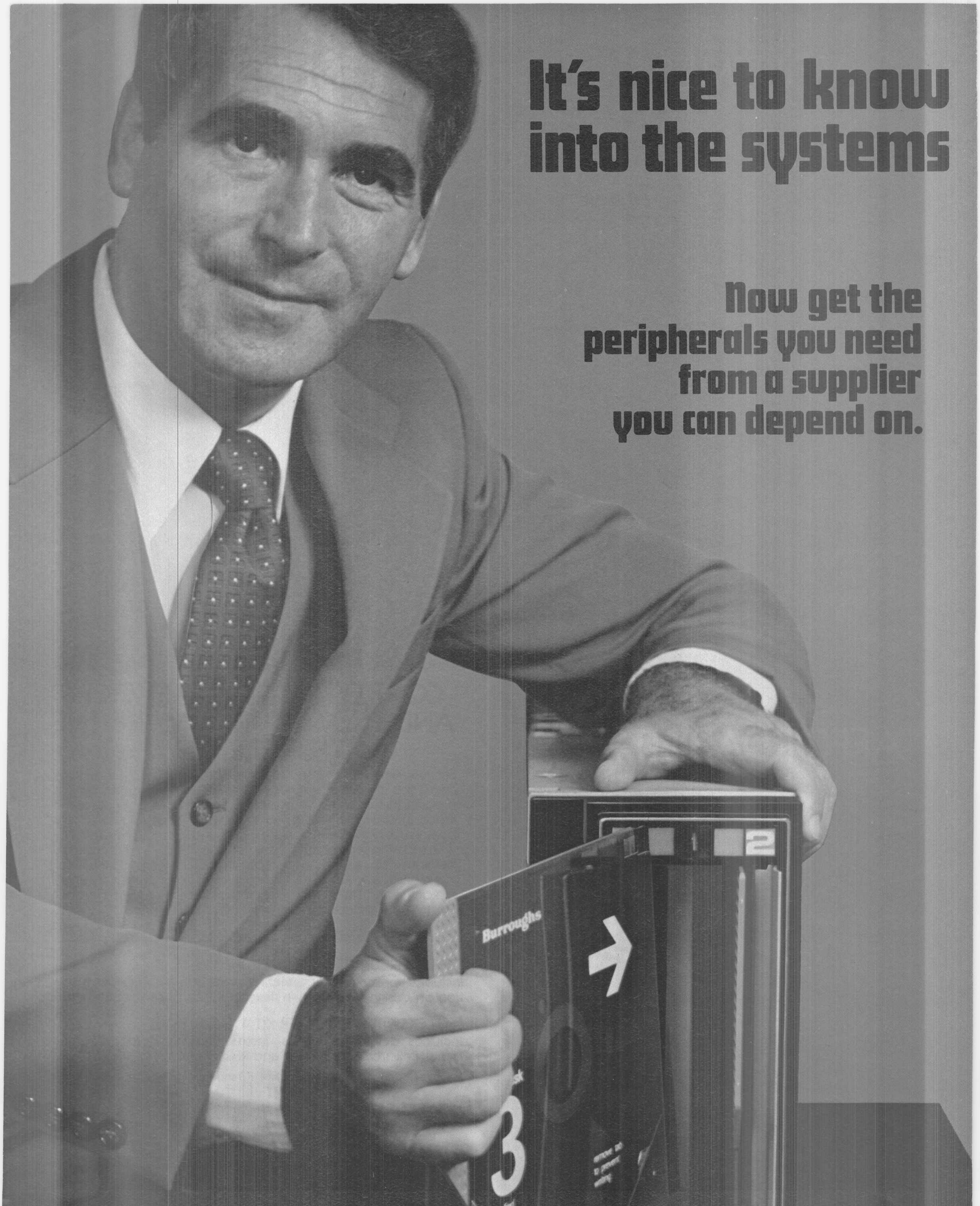
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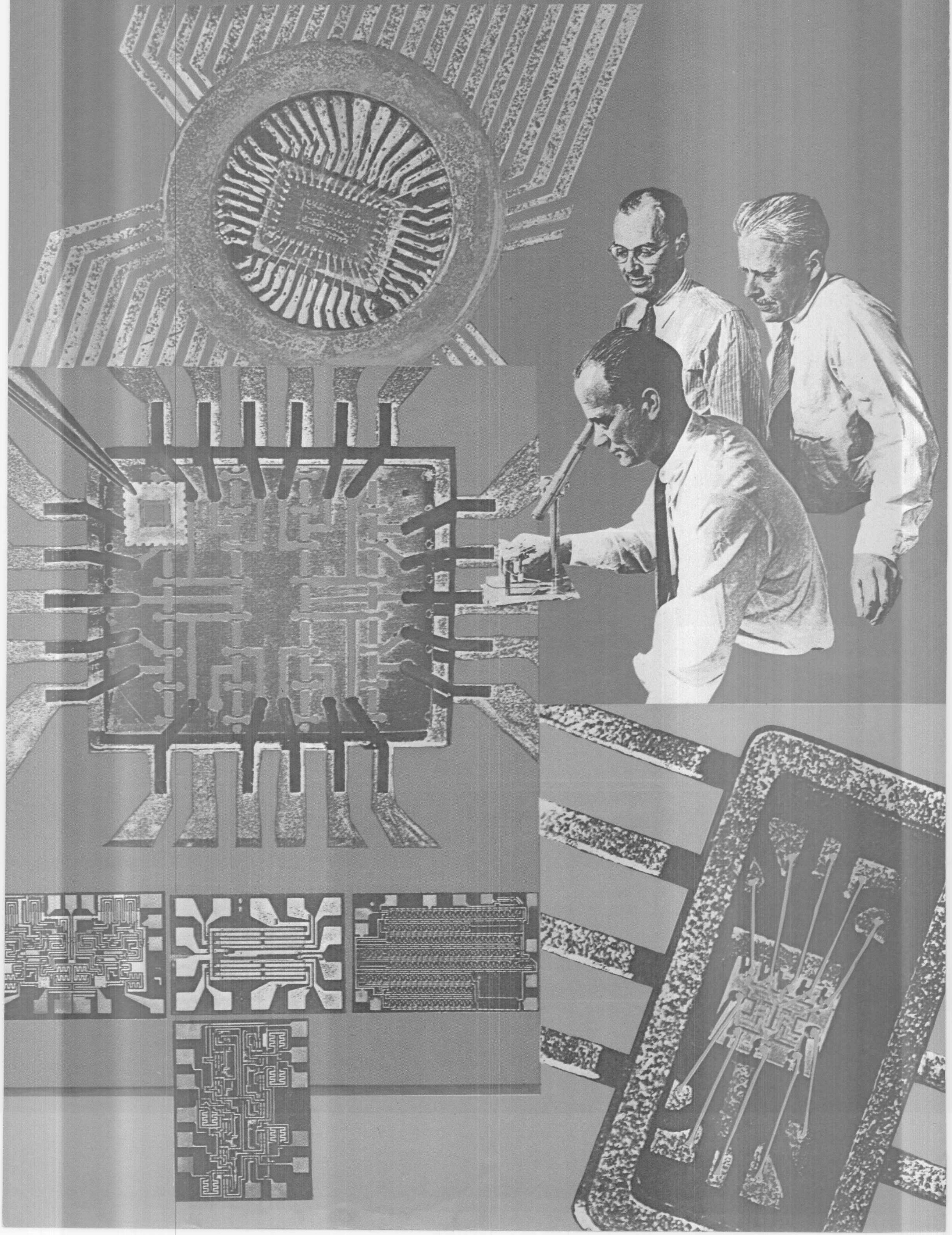


THE SOLID-STATE ERA

FARADAY'S OBSERVATION, BACK IN 1833, OF SILVER SULFIDE'S QUIRKINESS STARTED SOLID-STATE ELECTRONICS ON ITS LONG AND DIFFICULT PATH TO THE DEVELOPMENT OF THE TRANSISTOR IN 1947 AND THE INTEGRATED CIRCUIT IN THE LATE FIFTIES. SCHRÖDINGER'S QUANTUM MECHANICAL THEORY WAS NEEDED TO EXPLAIN THE BEHAVIOR OF SEMICONDUCTORS; ALCHEMY SEEMINGLY WAS NEEDED TO MAKE THEM. NONETHELESS SEMICONDUCTOR TECHNOLOGY BEGAT AN ADVENTUROUS NEW INDUSTRY THAT HELPED LAUNCH THE MISSILE AND SPACE PROGRAMS OF THE SIXTIES, ACCELERATED THE SPREAD OF COMPUTERS IN THE SEVENTIES, AND MADE MILLIONS FOR ITS FORTUNATE FOUNDERS.

Chapter 5

When Bell Telephone Laboratories announced the invention of the transistor, the general press treated the development almost indifferently. The New York Times carried the news the next day, July 1, 1948, on the next to the last page of the paper. It ran, four paragraphs, as the last item in "The News of Radio" column:

"A device called a transistor, which has several applications in radio where a vacuum tube ordinarily is employed, was demonstrated for the first time yesterday at Bell Telephone Laboratories, 463 West Street, where it was invented.

"The device was demonstrated in a radio receiver, which contained none of the conventional tubes. It also was shown in a telephone system and in a television unit controlled by a receiver on a lower floor. In each case the transistor was employed as an amplifier, although it is claimed that it also can be used as an oscillator in that it will create and send radio waves.

"In the shape of a small metal cylinder about a half-inch long, the transistor contains no vacuum, grid, plate or glass envelope to keep the air away. Its action is instantaneous, there being no warm-up delay since no heat is developed as in a vacuum tube.

"The working parts of the device consist solely of two fine wires that run down to a pinhead of solid semiconductive material soldered to a metal base. The substance on the metal base amplifies the current carried to it by one wire and the other wire carries away the amplified current."

Even technical journals were slow to appreciate the inherent possibilities of the transistor. To stir enthusiasm for the device, Bell Laboratories licensed it freely and publicized it extensively in seminars and papers.

Within laboratories in the United States and Europe, however, interest in what later came to be called semiconductors had long roots. Early dealings with the electrical properties of semiconductors can be traced to the last century, when several scientists independently studied the photovoltaic and rectifying effects of certain compounds like silver or zinc sulfide and elements like selenium. Following Faraday's discovery in 1833 that the conductivity of silver sulfide increases with temperature (while metals display an opposite effect), Alexander-Edmond Becquerel of France discovered in 1839 that he could generate a voltage by illuminating the junction of an electrolyte and what was only a century later to be termed a semiconductor.

Willoughby Smith in 1873 noted a change in the conductivity of selenium under illumination, and a year later Ferdinand Braun, a professor of physics in Marburg, Germany, established the rectifying property of a "cat's whisker" contact of metal wire on galena (lead sulfide), thus creating the first metal-semiconductor junction. This cat's whisker diode detector served for a time as a somewhat temperamental detector of the radio-frequency signals generated at that time by spark-gap transmitters. Its decline began with the invention of the vacuum-tube diode by Fleming in 1904, and its virtual demise was ensured by the development in 1906 of Lee de Forest's triode; both were far more reliable operation. In fact, interest in solid-state phenomena was not to re-emerge until after World War I.

When the solid state did receive renewed attention, Bell Telephone Laboratories was among the curious. The idea of using some kind of electronic switch other than the vacuum tube to replace the telephone system's mechanical switches surfaced there in 1936, and by 1945 the Bell center was charting a deliberate course of wide-ranging research in solid-state physics aimed at developing what became the transistor.

But laboratory success did not end the struggle. It was David meeting Goliath. In 1948 the vacuum tube was a highly sophisticated commercial product. It was fragile, true; but so was the first transistor. And the transistor called for totally new production methods and system designs, and at first it was very expensive.

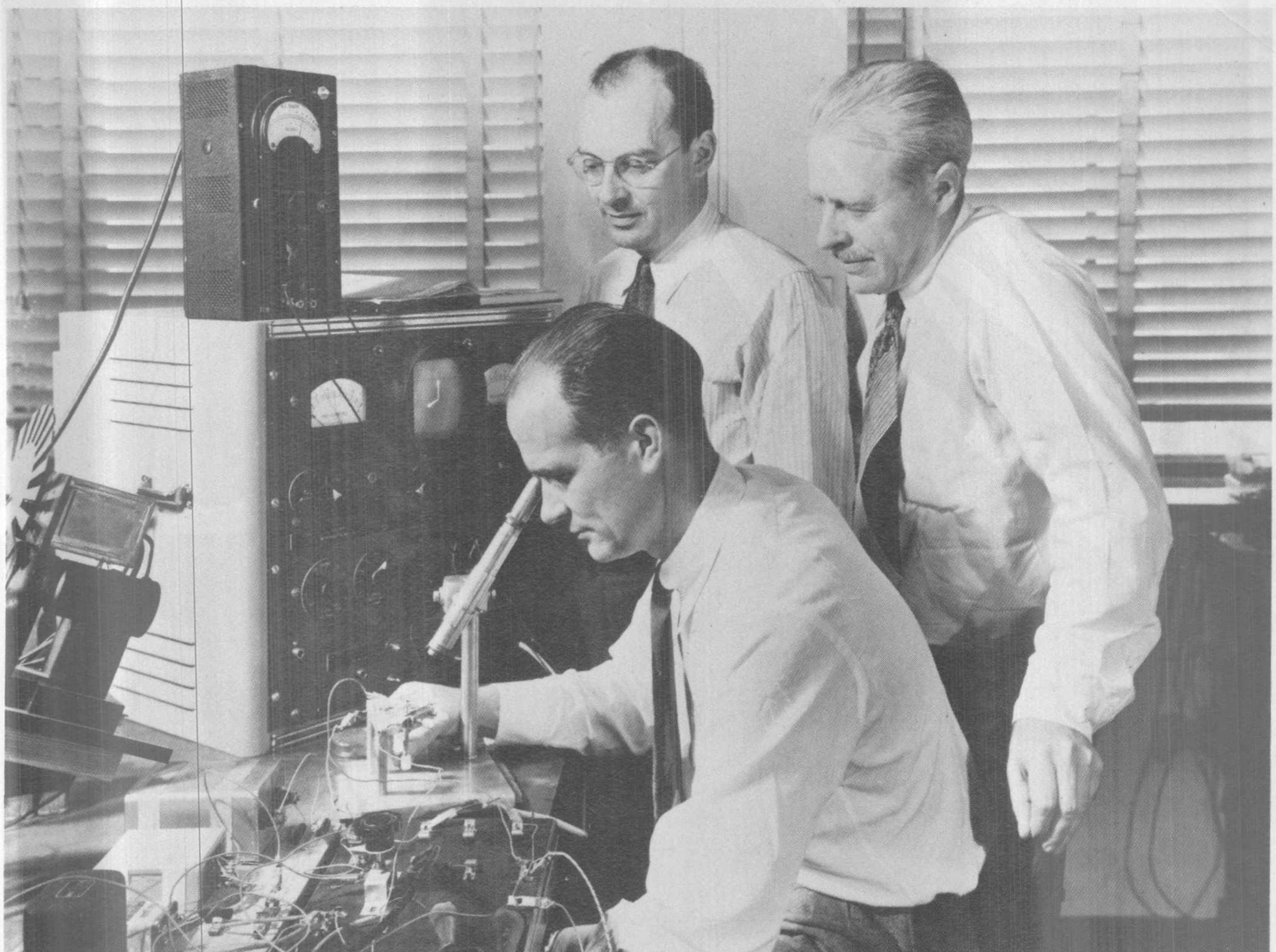
Still, because of the new device's small size and weight and low power consumption, the military became a customer immediately, as did hearing-aid manufacturers. What tipped the scales fully toward the transistor was the influence of computers and their need for huge quantities of small, low-power switches, as well as their ultimate digitization of much system design.

But if any one factor can be given most credit for the birth of the transistor, it is intellectual curiosity. More than any other electronic device, the transistor had its origins in scientific theory rather than in technological developments.

The year was 1900, and postulation of a quantum hypothesis by Max Planck provided a basis for atomic theory and ultimately for the theory that explained the behavior of electrons in solids. It was from Planck's work that Albert Einstein was able to explain Becquerel's photoelectric effect in 1905. Though early researchers had deduced that photons caused the emission of electrons from certain materials, until Planck and Einstein there was no explanation of this puzzling question: why, if the number of electrons emitted is proportional to the intensity of light, is their energy proportional to the wavelength of the light? The quantum theory proposed a dual wave/particle nature of photons: if light actually comprises small packets whose energy is proportional to the wavelength, the experimental data could be satisfactorily explained.

Studies of the photoelectric effect were carried out in science centers throughout the world. R. W. Pohl, a young physicist in Berlin, as well as Wilhelm Röntgen, the German physicist who discovered X rays, studied that effect and the luminescent properties of solids. The problems of those times were to plague solid-state scientists right through to the birth of the transistor—namely, lack of pure substances.

By the start of the 1920s, it was generally accepted that metals were good conductors because they offered readily available electrons. In the presence of an electric field, these would be transported in a single direction to conduct electricity, and the same electrons could similarly transport kinetic energy to conduct heat. However,



Pioneers. In 1947, physicists William Shockley (seated), John Bardeen (left), and Walter H. Brattain of Bell Telephone Laboratories developed the point-contact transistor—the first solid-state amplifier. The three received the Nobel Prize in physics in 1956.

a way to quantify the behavior of electrons in solids had to await Erwin Schrödinger's famous quantum-mechanical equation, which the Austrian physicist published in 1926. Within the next 10 years eager physicists were assisted by the equation, which tied together all the puzzling solid-state phenomena encountered during the preceding century.

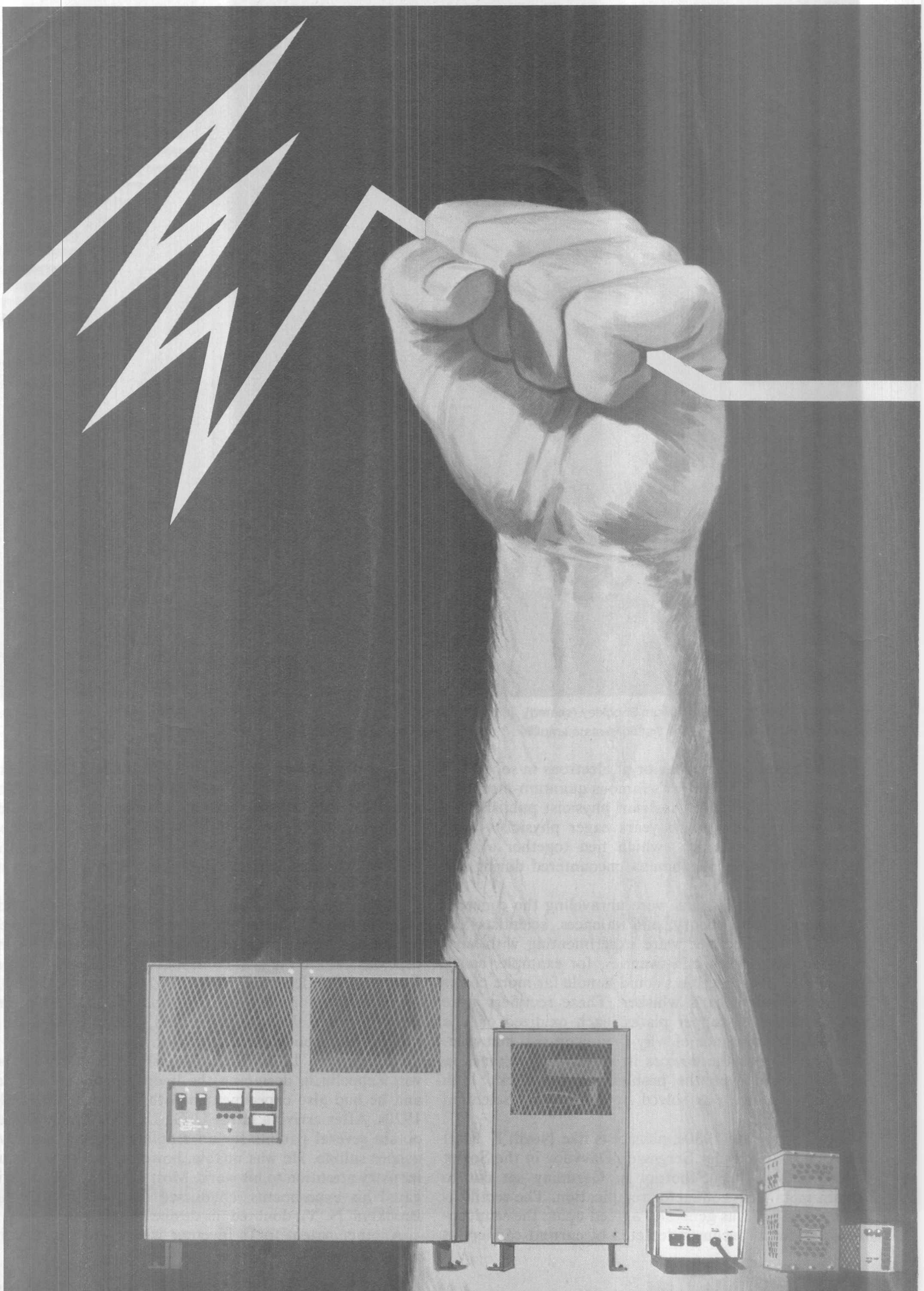
While the theoreticians were unraveling the concepts of electrons, band theory, and valences, scientists less mathematically inclined were experimenting with various materials. In the mid-twenties, for example, newly devised solid-state rectifiers could handle far more power than the sensitive cat's whisker. These rectifiers were built of stacks of copper plates, each oxidized on one side. Despite ignorance of why they operated, manufacturers turned out the devices in substantial volumes in the 1930s, and even the problem of the stacks' high forward resistance was solved by substituting selenium for the oxide.

Then, in the late 1930s, physicists like Nevill F. Mott in England, Alexander Sergevich Davydov in the Soviet Union, and Walter Schottky in Germany set out to explain metal-semiconductor rectification. The rectification mechanism was generally agreed upon: the semiconductor material becomes depleted of current carriers at the junction, which creates an effective barrier to equilibrium electron flow across the junction. Application of an electric field that reduces the barrier—a higher potential on the semiconductor side—permits electron flow, while reversal of that field further depletes the semiconductor of carriers, thus heightening the barrier to electron flow.

Many inventors struggled with the notion of a solid-state amplifier. The more common attempts were based on the field-effect principle, most likely because its concept was akin to the grid-control action of vacuum tubes. The first recorded attempt in the United States dates to 1925, when a former professor of physics at the University of Leipzig, Julius E. Lilienfeld, began working on a concept for a solid crystal amplifier.

In Germany, Lilienfeld had assisted Count Ferdinand von Zeppelin in designing the hydrogen-filled dirigible, and he had also experimented with X rays in the early 1920s. After arriving in the U. S., Lilienfeld managed to obtain several patents for an amplifier design based on copper sulfide. He was unable, however, to draw serious industry attention to his work. Most of those who investigated his experiments, conducted in near obscurity in Brooklyn, N. Y., doubted his devices would work at all.

Another patent to an inventor who could not explain



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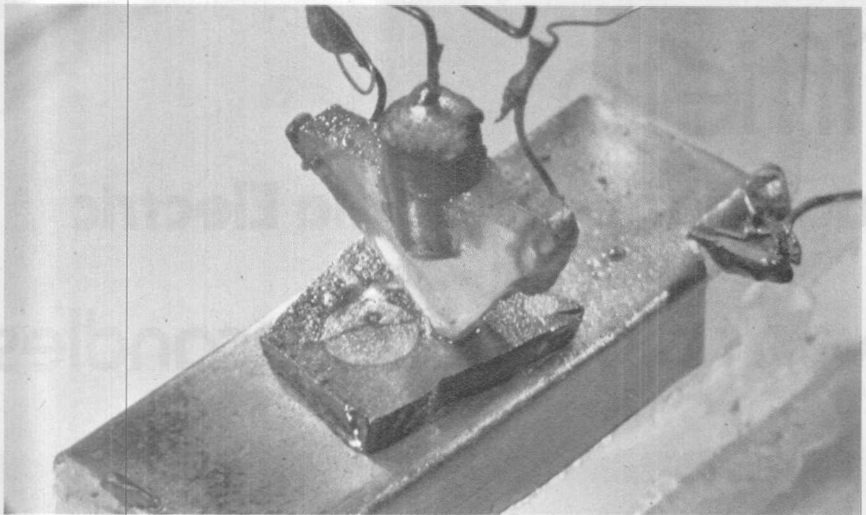

Solid amplifier. The first transistor placed two closely spaced contacts (the emitter and collector) on the surface of a germanium slab (the base). The V-shaped object is a plastic triangle round which gold foil was wrapped and slit at the apex with a razor; it was held on the slab by spring pressure.

the theory behind his device was issued in 1935 by Britain to Oskar Heil for a field-effect triode. Heil, a German inventor, proposed the use of a control electrode to regulate current flow through a thin semiconductor layer. The materials included copper oxide, vanadium pentoxide, tellurium, and iodine. Though it is doubtful that Heil's device ever actually worked, his design was a precursor of the insulated-gate field-effect transistor, since the control electrode was isolated from the semiconductor substrate.

Pohl meanwhile went on from his early experiments in photoelectricity to develop a working crystal amplifier in 1938. Though impractical—a slow-acting triode that relied on a wire grid to control the flow of electrons through a heated potassium bromide crystal—the device nonetheless proved to him the theoretical feasibility of solid-state amplification.

It is ironic that although the concept of a field-effect solid-state amplifier is marvelously simple, the development of a practical device was destined to come after the invention of a far more complex amplifier—the bipolar transistor. All the field-effect transistor called for was modulation of the current flowing through a chunk of semiconductor material by injection of charge carriers through a gate or grid, and the latter could even be insulated from the slab. But the key to development lay in the formation of surface states: the injected charge carriers could not affect the flow of current through the semiconductor slab because they got trapped in the material's surface. Ignorance of these surface states delayed the advent of the field-effect transistor—and the bipolar transistor as well.

In retrospect, it is not surprising that the first practical solid-state amplifier was developed by Bell Telephone Laboratories, then in New York City and now headquartered in Murray Hill, N. J. It was in 1948, and is now, the largest industrial research and development organization in the world (in 1978 it employed over 19,000 people and produced 13,757 technical papers and 296 patents). At Bell, which researches every aspect of its telecommunications business, the disciplines of metallurgy, chemistry, materials science, solid-state physics, and engineering were already present; they just needed to be organized toward the goal of a solid-state amplifier.

Bell's research into solid-state physics was an offshoot of vacuum-tube research that dealt with thermionic emission and other surface properties of metals. Walter H. Brattain, one of the three men who were to play the leading roles in the invention of the transistor, was assigned to this vacuum-tube research when he joined Bell Laboratories in 1929. Brattain had received a Ph.D. from the University of Minnesota, where physicists like Schrödinger, James Franck, and Arnold Sommerfeld were guest lecturers on the new theory of quantum mechanics. Brattain's background in solid-state physics gave him a leaning toward semiconductors, and in 1931 he was reassigned at the Bell center to study the copper oxide rectifier with J. A. Becker.

Brattain and Becker were convinced that the rectifying action took place at the immediate junction of the metal and copper oxide and that current flow through the materials themselves was ohmic. These findings were confirmed by experiments in photoelectricity, in which a current flow was produced solely by illumination of the junction and not of the bulk materials. Like many other scientists of their period, the Bell researchers also struggled with the notion of how to add a third electrode—a control grid—to the rectifier to make an amplifier.

Fortunately, while Brattain was doing his practical research on rectifiers through the early 1930s, the theoretical work on semiconductors was progressing all over the world. In 1931, the British physicist Alan H. Wilson published his theoretical model of a solid semiconductor, which related earlier work on the motion of electrons in metals to insulators and semiconductors. And within the next few years there came the contributions on semiconductor theory from Mott in England, Yakob Ilyich Frenkel and Davydov in the Soviet Union, and Schottky in Germany. As these physicists lectured and published,

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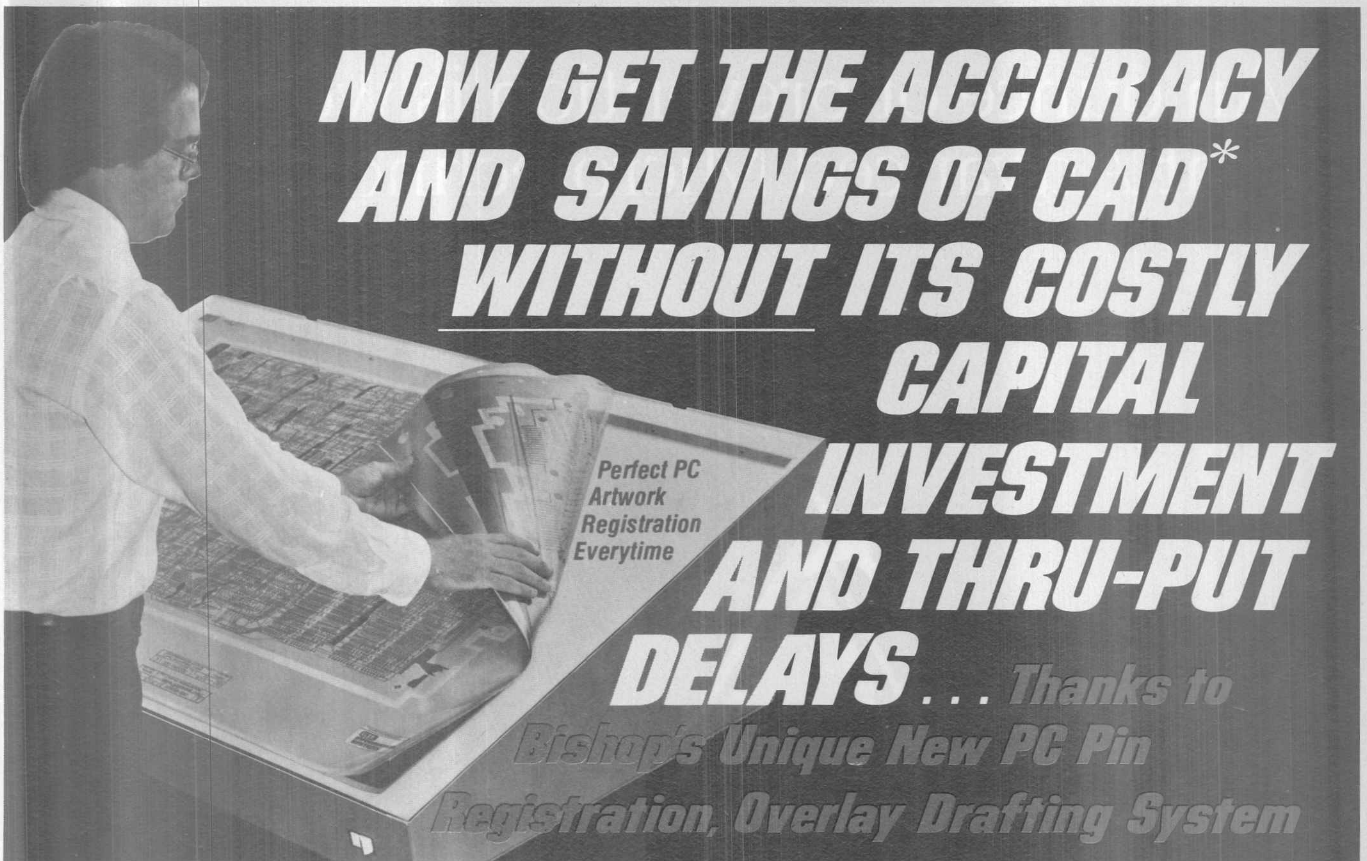

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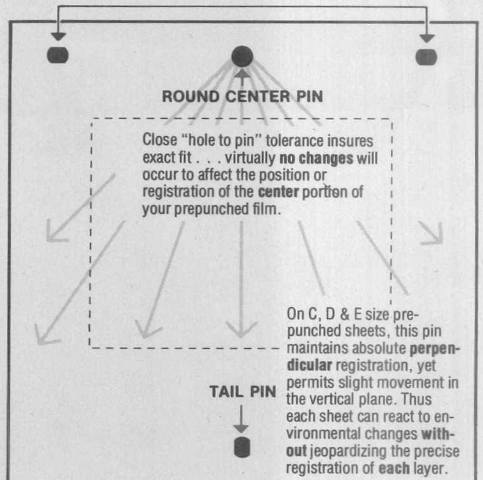

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where it was absorbed eagerly by young graduate students. One such student was William Shockley, the youngest of the three key developers of the transistor.

Shockley joined Bell Laboratories immediately after receiving his doctorate in physics from the Massachusetts Institute of Technology in 1936. He had studied under John Slater, a major contributor to the development of quantum mechanics and its application to the solid state. At Bell, Shockley was first told to report to C. J. Davidson in the vacuum-tube development department. Davidson, with a colleague, Lester Germer, had been the first to observe electron diffraction, for which the two received the Nobel Prize in 1937. But for Shockley, it was only a short tour of duty with the vacuum tube. After working on multiplier tubes, he was assigned to his preferred area of study, solid-state physics.

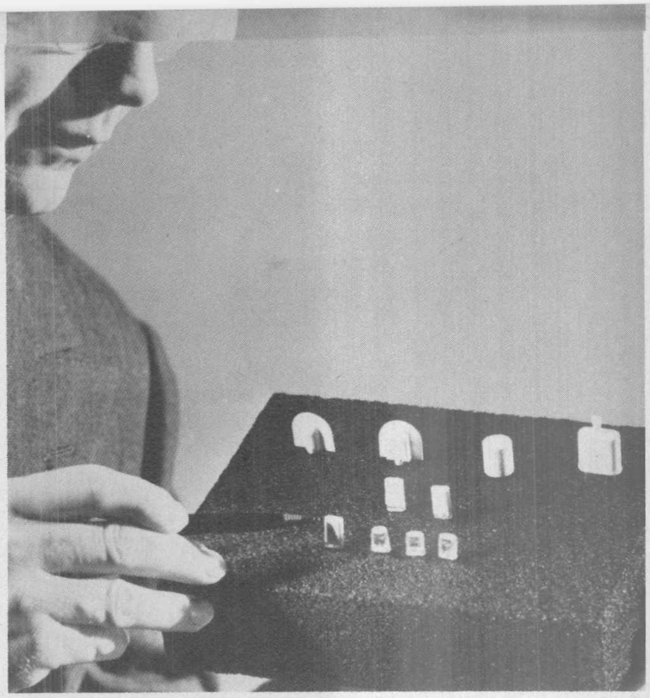
The man perhaps most responsible for planting the idea of the transistor in Shockley was Mervin Kelly, then director of research and later president of Bell Laboratories. As early as 1936, Kelly had expressed his belief to Shockley that for the growing needs of communications to be met, the phone company's mechanical switching must eventually be replaced with electronic switches of some sort. Shockley was left with an indelible impression. He was certain Kelly was not referring to a new tube technology, but something radically different.

Inevitably Brattain and Shockley crossed paths in the late 1930s. Shockley became involved in Brattain's and Becker's research on copper oxide rectifiers, and on Dec. 29, 1939, Shockley made his first notebook entry on a proposed semiconductor amplifier built of copper oxide. He had studied Schottky's theory on the space-charge region—the surface layer of the semiconductor near its junction with the metal—and had noted that this layer gets depleted of carriers in the presence of a reverse field potential. It set Shockley to thinking: why couldn't the spreading of the depletion layer under an increased electric field somehow be used as a valve to regulate current flow? He recorded in his notebook:

"It has occurred to me that an amplifier using semiconductors rather than vacuum is in principle possible. Suppose, for example, that a very fine mesh copper screen is oxidized, thus giving a metal grid embedded in oxide, and let the ohmic contacts be made to the outer surfaces. Then if the carriers of charge are for convenience regarded as positive, if the grid is made plus, a space-charge sheath with carrier deficit forms around it. This gives a region of low conductivity and accounts for high resistance in the reverse direction for the rectifying junction . . .

"We can say that the grid effectively can be used to raise the resistance in its vicinity and thereby hinder the flow of current. . . . Since the grid is being used in the reverse direction, its resistance is high and it will not consume much power, whereas relatively large currents . . . can be controlled."

Shockley's idea, however, only amused Brattain. With Becker, he had abandoned any hope a year earlier of burying a grid in the space-charge region of a copper oxide rectifier. They had based their pessimism on calculations of the microscopic dimensions involved. Still,



Shaping up. By 1952, germanium transistors had begun to take on standard shapes and pin configurations. The three rightmost transistors in the front row are point-contact devices; the rest—including the power transistors in the rear row—are junction types.

because Brattain was well aware of the importance of such a development, he began experiments with Shockley using oxidized copper wire.

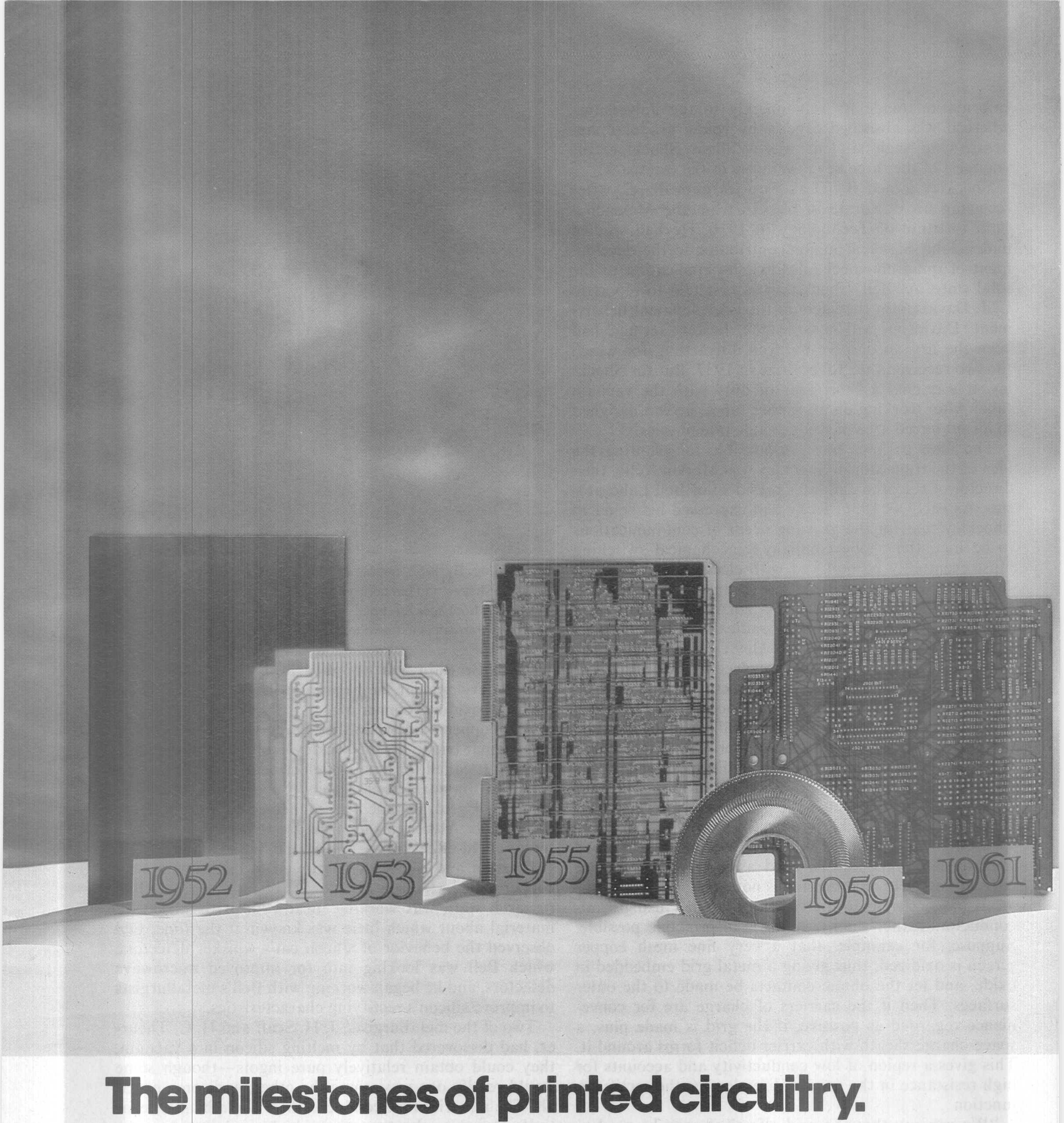
The copper oxide amplifier never worked. Following his original triode idea, Shockley proposed an improved version. It called for a pair of electrodes to make contact with the top surface of a thin copper oxide slab. The control, or grid, voltage was connected to the underside of the slab. Although the structure strikingly resembled today's field-effect transistors, it, too, failed.

Brattain and Shockley continued to experiment with copper oxide. Russell S. Ohl, a chemist on the Bell research staff, was working meanwhile with silicon—a material about which little was known at the time. Ohl observed the behavior of silicon cat's whisker detectors, which Bell was looking into for improved microwave detectors, and he began working with Bell's metallurgists to improve silicon's rectifying characteristics.

Two of the metallurgists, J. H. Scaff and H. C. Theurer, had discovered that by melting silicon in a vacuum, they could obtain relatively pure ingots—though some would rectify one way, some the other, and some not at all. The material that conducted best when biased negatively they named n type; that which conducted best the other way they called p type.

Scaff and Theuerer eventually discovered that what distinguished n silicon from p was the trace amount of impurity it contained. The actual level of impurity that doped the silicon p or n was exceedingly low—at that time it even defied spectroscopic detection. According to Brattain, the odor of the silicon ingots as they emerged from the oven had led Scaff to suspect the existence phosphorus contamination.

Further, the two metallurgists found that elements on



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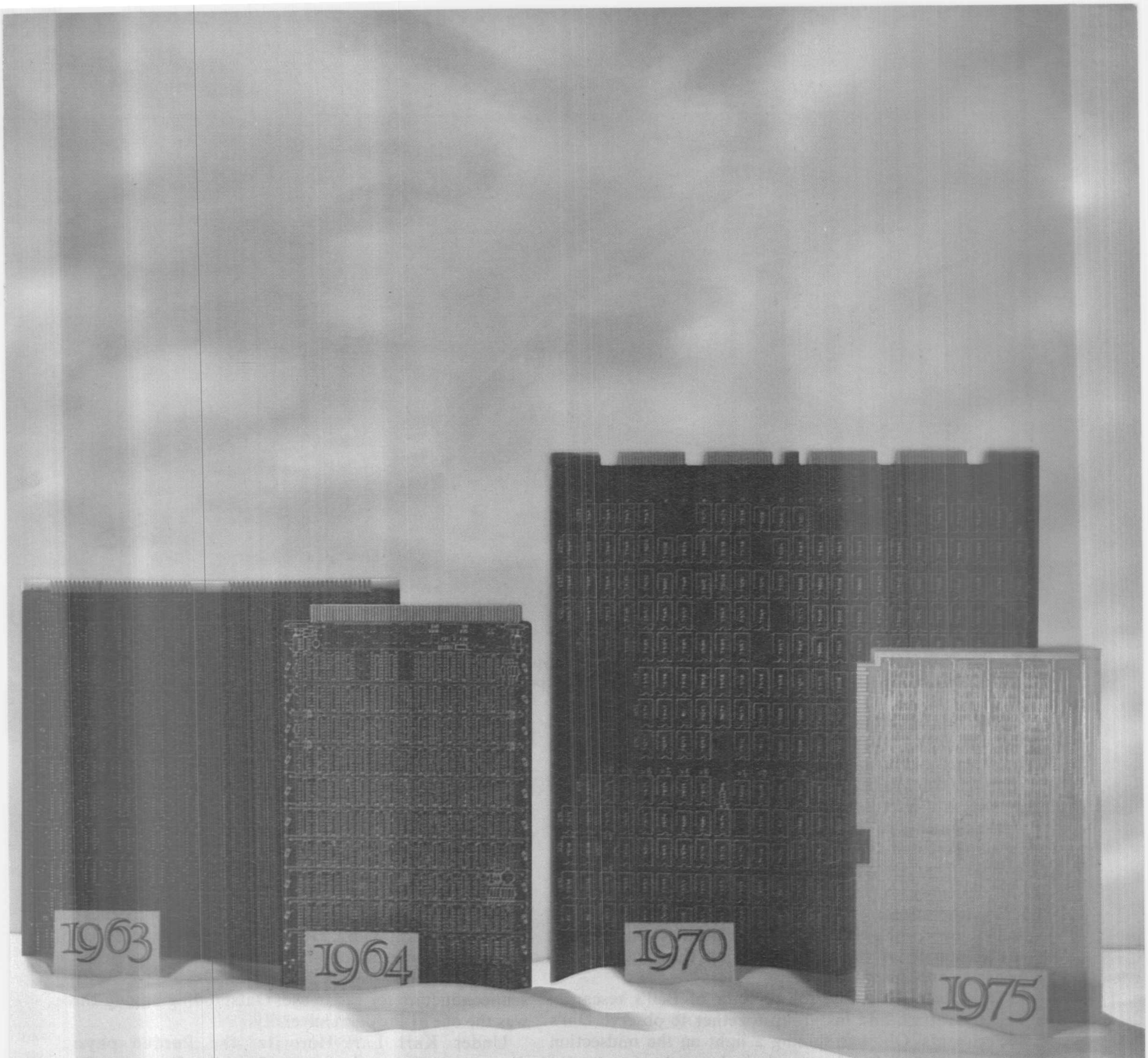
1963
1964
1970
1975

Transistorized. To prove the viability of transistors, RCA built prototypes of all-transistor radios, a TV set with a 5-inch screen, even an amplifier for an electric ukelele. The equipment was years from commercial production, though, since transistors then cost $15 or more.

either side of the fourth column in the periodic table of the elements—where silicon and germanium lie—could most easily produce the desired effect. Elements from the fifth column, like phosphorus and arsenic, provided an excess of electrons and thus made the material n type; those elements in the third column, including boron and indium, created an excess of holes, making the material p type. Brattain marveled at the elegant simplicity of this discovery.

In experiments, the metallurgists had grown a half-n, half-p ingot, thus creating the first pn junction. Ohl cut out a section of the ingot spanning the junction and began to experiment with it.

In early 1940 Kelly, the director of Bell's research, called Brattain and his group together to observe Ohl's experiments. Ohl was shining a light on the midsection of the silicon slab, whose ends had metal contacts and were connected to a voltmeter. As the meter deflected to a half volt, Brattain was awestruck. The reading was 10 times above any photoelectrically generated voltage he had ever seen. What's more, the light wasn't even shining on either of the metal-semiconductor junctions—it was focused somewhere in the center of the ordinary-looking black slab.

Of course, the light was illuminating a junction—the invisible pn junction in the silicon. But only after Brattain received his own piece of pn silicon to work with did he really believe what Ohl had demonstrated.

Though the stage seemed set now for the birth of the semiconductor triode, the outbreak of World War II interrupted the work of Shockley and Brattain. They were assigned to separate research groups involved in submarine-detecting radar. It was some six years before they were able to return to their work on solid-state amplifiers. Meanwhile minimal work with silicon was carried on at the Bell center during the war years; its aim primarily was to improve detectors for radar.

As it turned out, the war had a major impact on the development of the transistor. So important was the advancement of solid-state detectors for radar to the war effort that the U. S. government sponsored a program to investigate the properties of silicon and germanium. By 1943 no fewer than 30 laboratories in universities and industry were involved in federally funded research programs, all investigating semiconductors for radar use. Outstanding among these was the one at Purdue University.

Under Karl Lark-Horovitz, the Purdue physics department began its research in 1942 almost from scratch, since its strength during the 1930s had been primarily in nuclear physics. Research focused now on germanium. In less than four years, Purdue's staff of about a dozen scientists had so completely characterized germanium that its electrical properties could be predicted from its impurity content. The ratio of the material's hole mobility to its electron mobility was determined, and diodes with reverse breakdown voltages as high as 150 V were fabricated.

Although it had made a significant contribution to the future of semiconductor electronics, Purdue University all but abandoned its solid-state studies when World War II ended. Researchers often wonder whether Purdue might otherwise have invented the transistor itself, had it continued its research.

There is little doubt that Purdue's work provided key pieces to the solid-state amplifier puzzle. After the war


1977:
CTI develops separate hybrid microcircuit Driver and Receiver for MIL-STD-1553A and MDC A3818 (Model Nos. CT2077 and CT3078)
1978:
CTI develops first MIL-STD-1553B hybrid microcircuit Transceiver (Model No. CT3231)
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CTI develops an encapsulated module Remote Terminal Unit (Model No. CT1553-1)
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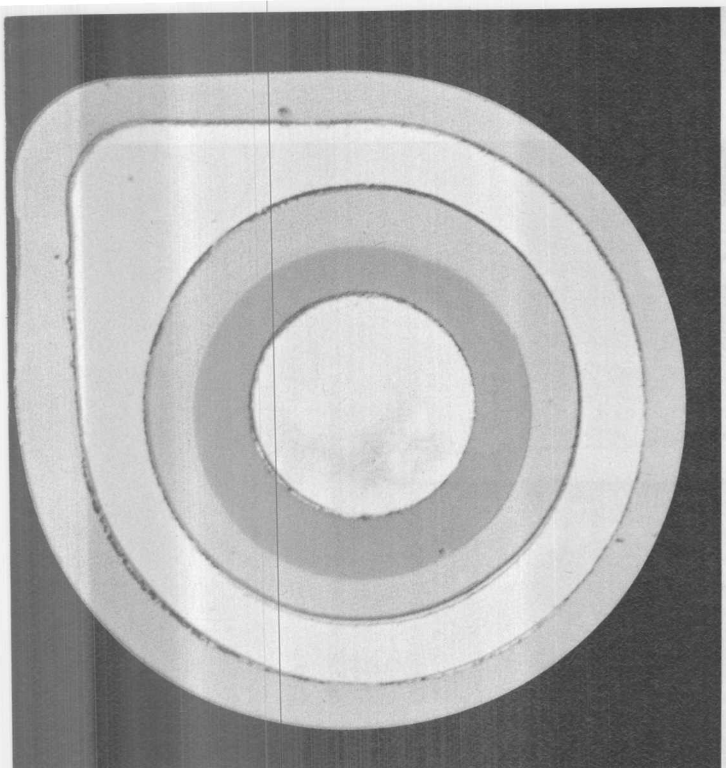


Planar. The transistor took on a new shape with Fairchild's planar process. So named because it was flat, the planar transistor diffused the emitter region (center) into the base region (tear shape), which itself was diffused into the collector substrate.

Bell Laboratories' research concentrated almost exclusively on germanium, whose properties now were far more clearly understood than those of silicon. But aside from this work and other studies at the International Business Machines Corp. and a handful of other companies, not many laboratories were left with a lively interest in semiconductors. The wartime research effort—except for the work on solid-state radar detectors—had turned the electronics industry predominantly back toward more applicable research in the area of vacuum tubes.

Bell knew where it was headed, however, even before the war had ended. On April 9, 1945—five months before V-J Day—a meeting on germanium crystals was held at the research center, and representatives of all Bell wartime semiconductor research laboratories were present. Three months later Bell issued its "Authorization for Work" on solid-state materials—the document that led to the establishment of the center's semiconductor group, from which the transistor emerged. The internal Bell Laboratories document, which went on for several pages, began:

"Subject: Solid State Physics—the fundamental investigation of conductors, semiconductors, dielectrics, insulators, piezoelectric and magnetic materials.

"Statement: Communication apparatus is dependent upon these materials for most of its functional properties. The research carried out under this case has as its purpose the obtaining of new knowledge that can be used in the development of completely new and improved components and apparatus elements of communication systems . . . The modern conception of the constitution of solids that has resulted indicates that there are great possibilities of producing new and useful properties by finding physical and chemical methods of controlling the arrangement and behavior of the atoms and electrons which compose solids."

It was just a few months after this that a solid-state physics group was established at Bell Laboratories under Shockley and Stanley O. Morgan. Within the group were many subgroups, one of which—semiconductors—included Brattain and Gerald Pearson, an experimental physicist. In the fall of 1945, Brattain and Pearson were joined by John Bardeen, a physicist returning to his field after a five-year wartime assignment with the Naval Ordnance Laboratory.

Bardeen, who knew Fisk and Shockley from college days in Boston, had had no introduction to semiconductors before arriving at the Bell center. He had, however, received a doctorate in solid-state physics from Princeton and had later, like Brattain, studied quantum mechanics under John H. Van Vleck at Harvard.

Bardeen at first shared an office with Brattain and Pearson. Like the others, he was eager to immerse himself in the study of solid-state physics, having shelved his prewar interest in it while on wartime assignment. That interlude, he later maintained, actually contributed to the group's creativity and zeal.

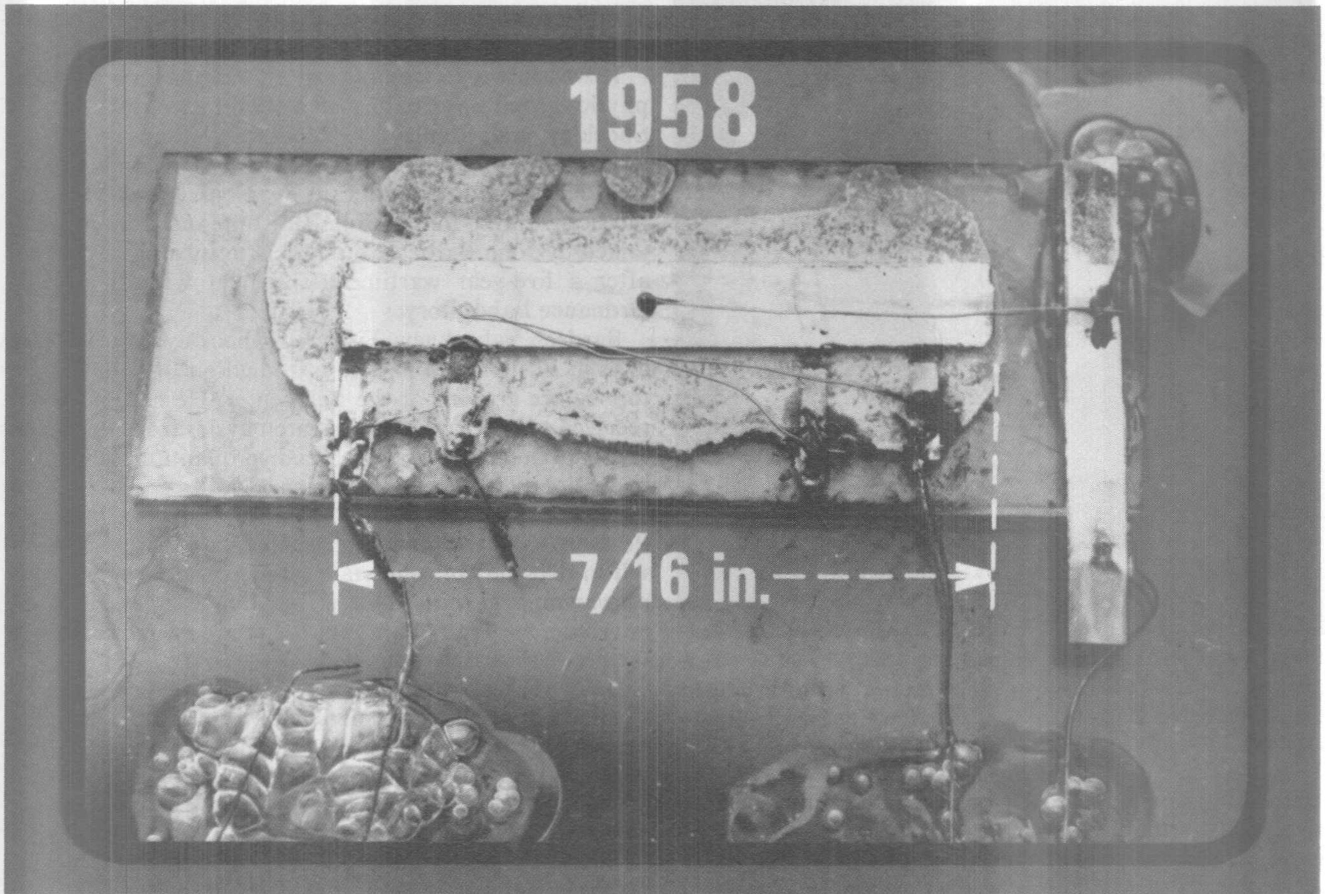
"We were able to take advantage of the important advances made in that period in connection with the development of silicon and germanium detectors, and at the same time have a fresh look at the problems," he said in the lecture he gave upon receiving the Nobel Prize in physics in 1956.

One of the first major decisions made by the semiconductor group was to restrict research to germanium and silicon, the simplest semiconductors. The group believed that the only explanation for the continued lack of understanding of semiconductors—despite intensive worldwide research—was the diffuse experimentation on so many different complex materials. Silicon and germanium, on the other hand, were elemental, simple; moreover, their atomic structure had revealed the same strong covalent bonding as a diamond, and thus their crystals tended to be strikingly free of defects.

Initial work in the semiconductor group picked up on Shockley's original field-effect concept for a triode. Based on the Mott-Schottky theory of rectification, the group reasoned, it should be possible to control the density of electrons near the surface of a semiconductor by applying an electric field between the surface and a metal electrode insulated from the surface. Nevertheless every experiment failed.

Brattain and Bardeen set out to explain these failures. The lead they had followed stemmed from Schottky's field-effect theory, which stated that the number of free electrons in a semiconductor was the same at the surface as in the interior. In fact, Brattain discovered that Schottky's theory did not hold up. He learned this by comparing the rectifying properties of different metal contacts to a semiconductor. Bardeen then proposed a hypothesis that evolved into one of his most important contributions to electronics: the theory of surface states.

Bardeen theorized that a semiconductor surface must



First integrated circuit. The first IC, developed at Texas Instruments Inc., proved an entire circuit could be built with silicon. The bars, actually sections from a wafer of mesa transistors, became breadboards in this oscillator using silicon as resistors, capacitors, and transistors.

be in equilibrium even before any electrical contact is made to it. For that to be so, any electrons trapped at the surface must be neutralized by a space charge region equal and opposite to the electrons' charge at the surface. This would explain why Schottky rectification took place with little bearing on the type of contact metal used: it was the electrostatic potential change between the interior of the semiconductor and its surface that did the rectifying.

With this new theory, Brattain and Bardeen undertook a series of experiments to gain a better understanding of surface states. One experiment, which was suggested by Shockley, was to determine if the trapping centers for electrons at the surface were limited. The test involved comparing the contact potentials of semiconductor samples that differed in resistivity. The results were positive: the points where electrons were trapped were fixed in number.

Another experiment verified the existence of the electric field caused by the space-charge region. Carriers generated by illumination of the junction were apparently swept apart by that field, since a significant change in contact potential was measured.

The time was mid-December 1947, and though the bustle of Christmas had begun, the pace of experimentation at Bell quickened. Pearson and Bardeen proved by lowering the temperature of the semiconductor that electrons trapped at the surface could be frozen and their field effect detected. A follow-up attempt to measure the change in surface potential of germanium with temperature proved inconclusive; condensation interfered.

As a possible solution, it was suggested that entire apparatus—a semiconductor chunk with the contacts, reference electrodes, and wires used to measure contact potentials and photoelectric voltages—be immersed in an insulating liquid or an electrolyte. Varying the potential between the semiconductor surface and the reference electrode proved to change the photoelectrically generated voltage significantly. The group realized that it had found Shockley's field effect.

The week before Christmas an adaptation of that last experiment actually produced an amplifying triode. A potential applied between a drop of water surrounding a metal contact to silicon and the silicon slab itself could regulate current flowing from the semiconductor to the contact. Other liquids—electrolytes—gave even better results, but the group knew that the amplifier they were seeking could not use liquids. Attempts were made to use an evaporated gold film surrounding the point, but because of the tiny dimensions, a low-voltage arc destroyed the point contact.

Four days later, on Dec. 23, 1947, the group saw its greatest triumph. Bardeen and Brattain had decided that the thing to do was to get two contacts extremely close together on the surface of the semiconductor. By their calculations, the distance had to be no greater than 2

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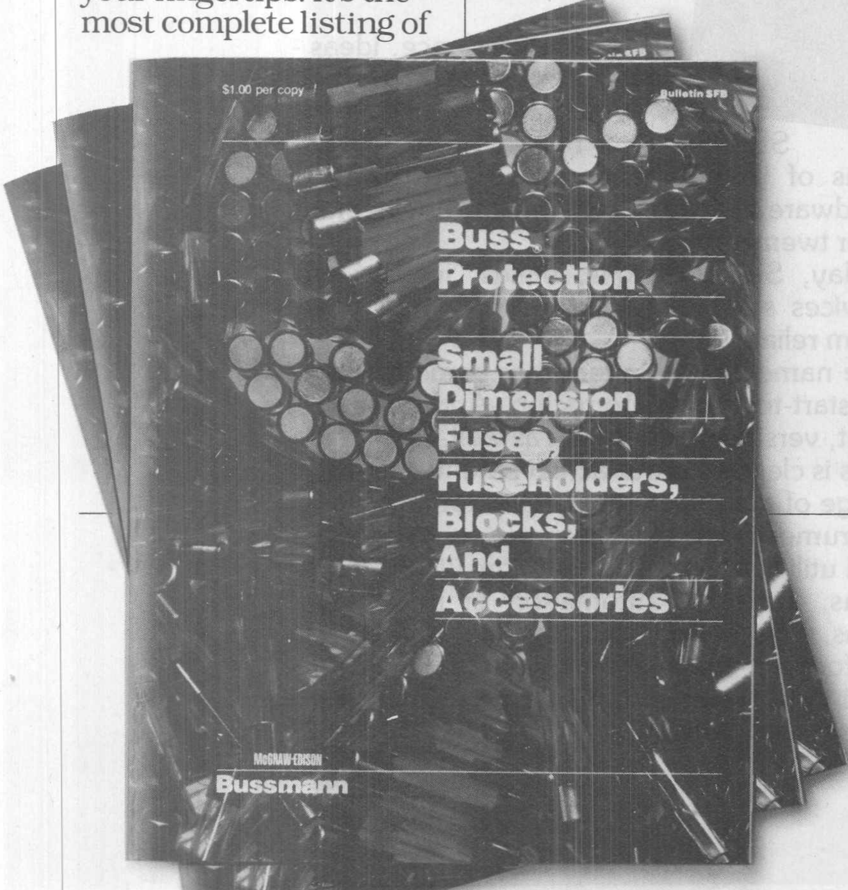

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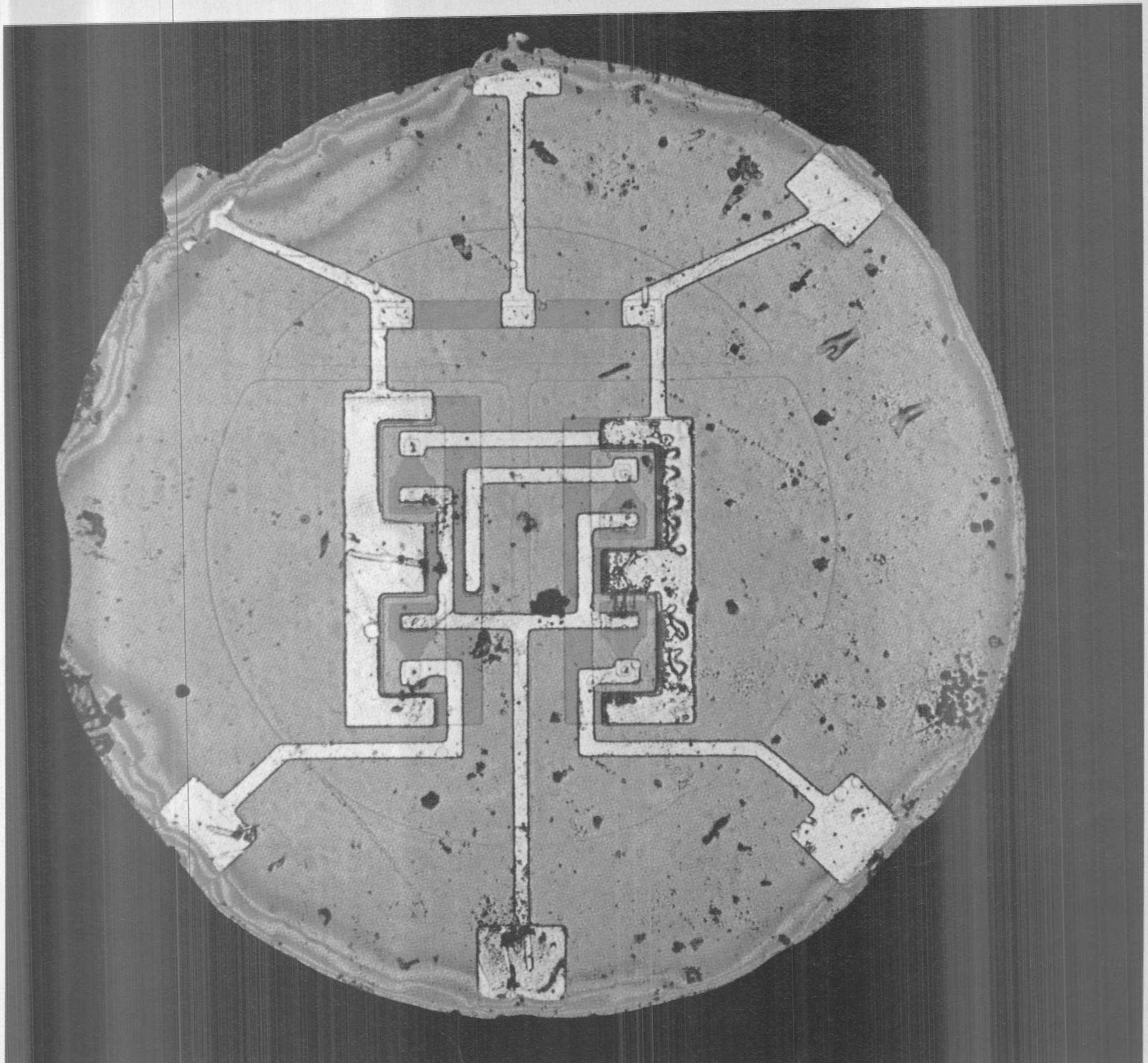

Flip-flop. The industry's first commercially available monolithic integrated circuit was this flip-flop from Fairchild Semiconductor, introduced in 1961. A member of the Micrologic family, the chip used resistor-transistor logic (RTL) and held four bipolar transistors and two resistors.

mils. That posed a problem, since the finest wire they had to work with was 5 mils in diameter. Brattain's ingenuity came to the rescue.

He cemented gold foil to the edge of a polystyrene triangle and sliced through the foil at the triangle's apex very carefully with a razor. The point was then set down on the semiconductor—germanium was used—and wiggled until both ends of the foil made good contact. One contact became the emitter, the other the collector, and the slab was the base.

Bardeen and Brattain had earlier discovered that a small potential on the emitter, positive with respect to the base, would inject holes into the semiconductor's surface and greatly increase its current-carrying capacity. Using that valve action, their amplifier achieved a voltage gain of about 100 that operated clear up to the audio range.

The original circuit was even spoken over that day and used the very next day to build an oscillator, dispelling any doubts that it was truly an amplifier. The only urgent problem left was what to call the invention.

The two had in mind a term in keeping with the varistor and thermistor, but they were at a loss for a suitable word. One day the subject came up when John R. Pierce was in Brattain's office. Pierce, better known for his work in satellite communications, proposed a name that fit the device's duality with vacuum tubes. The important parameter in a tube, he reasoned, is its transconductance, or ratio of output current to input voltage; the solid-state amplifier provided gain by trans-


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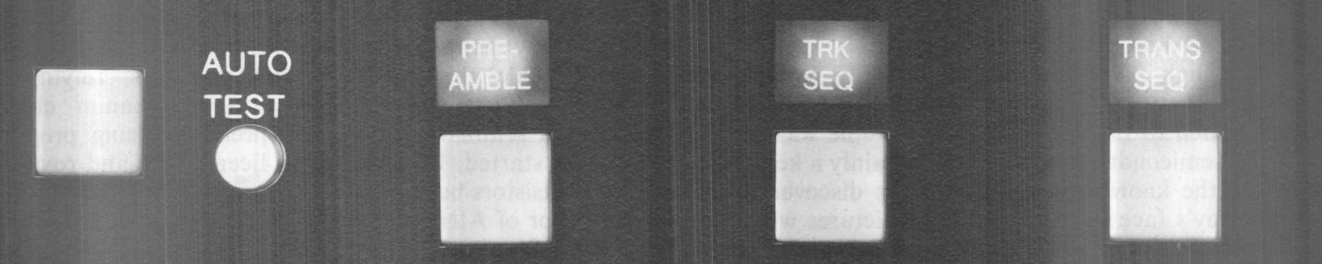

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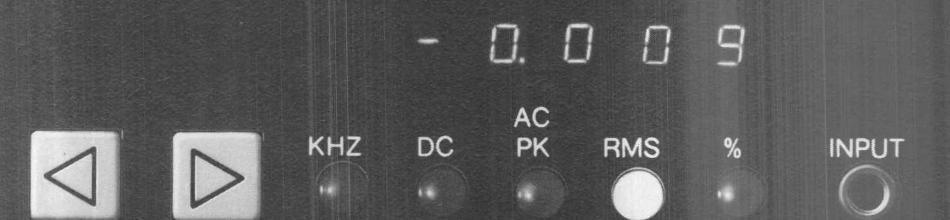

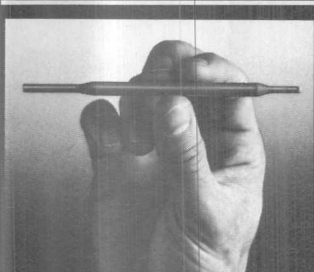

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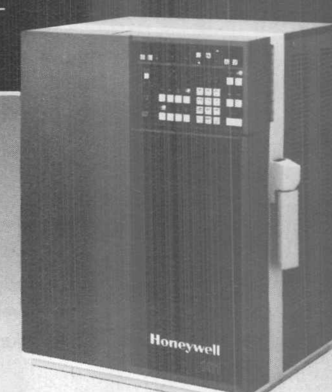

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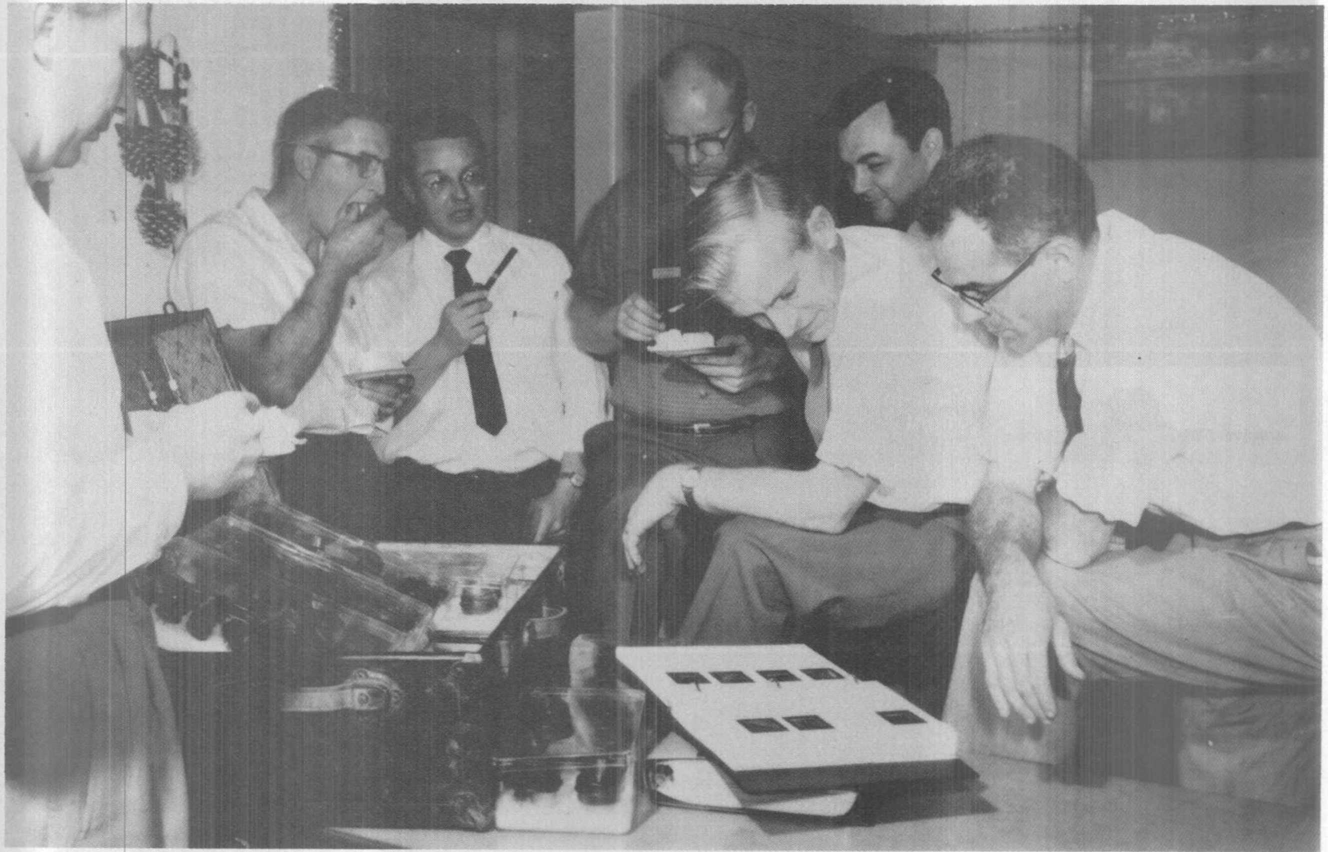
It was nearly seven months more before Bell Laboratories publicly announced its transistor. The semiconductor group needed that time to understand fully what the transistor effect involved, so that they could write a paper about it and apply for a patent for it. Also, the military had to be invited in to see if it thought the transistor should be guarded as a classified invention. But a brief glimpse of the device satisfied the military that that would not be necessary, and a week later its first public demonstration was held in New York on June 30, 1948. The lukewarm reception by the public, however, made it clear that the transistor would remain a laboratory rarity until more practical versions were made and designed into equipment.

Although Shockley had not actually participated in the discovery of the point-contact transistor—the patent was issued to Bardeen and Brattain—he was the leader of the semiconductor group and certainly a key contributor to the knowledge that led to its discovery. In fact, Shockley's face appears in all the pictures with the two coinventors, and he joined his colleagues in accepting science's highest accolade—the Nobel Prize in physics—for research on semiconductors and the discovery of the transistor effect in 1956. But all during the experimentation that led to the first transistor, Shockley maintained his earlier belief that a simpler, perhaps better device—a field-effect transistor—was possible. His frustration was increased by his inability to obtain a patent on his ideas because of the prior work by Pohl and Lilienfeld.

contact transistor, Shockley decided to abandon his quest for a field-effect transistor temporarily and to concentrate on another idea he had for a better bipolar device. He suggested that transistor action would still take place in a structure that sandwiched an n semiconductor region between two p regions. Shockley called the structure a junction transistor, but he was unable to verify its theory of operation simply because there was no way to build it at the time.

Meanwhile the electronics industry began to buzz with interest in the transistor. Bell Laboratories had decided that the way to get better, more reliable semiconductor devices was to stimulate industry production of them, for the early point-contact transistors were hardly more dependable than cat's whisker detectors, relying on springy wires pressed against a germanium chunk. Besides seminars and a widespread licensing program that it started, Bell waived all license fees and royalties on transistors built for use in hearing aids. This was done in honor of Alexander Graham Bell and his concern for the deaf.

But despite their promise, the first transistors were not received ecstatically by designers. Not only was their point-contact structure delicate, but the nature of their manufacture also rendered them difficult to match, inconsistent in characteristics, and quite expensive. All that characterizing a transistor meant in 1949 was figuring out its transfer resistance, usually given as a matrix of four parametric resistances. The industry had a long



TTL celebration. After the development in 1961 of transistor-coupled transistor logic (TCTL)—the forerunner of TTL—members of the design team at Pacific Semiconductors Inc., a small Culver City, Calif., company, celebrated the award of the patent to James L. Buie, left.

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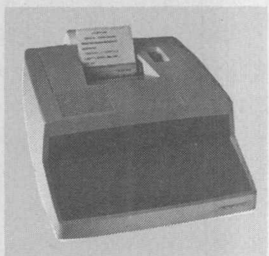

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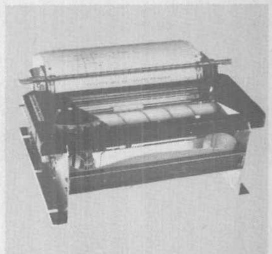

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way to go to standardize the specifications for these radically new devices.

The inadequacies of transistors aside, there was another reason for the reluctance of industry to adapt to solid-state electronics. Many engineers had grown up with vacuum tubes and felt a strong resentment toward the upstart transistor. It may have been billed as a replacement for the tube, but it was clearly no in-circuit replacement—its supply voltages, power capability, even its very operation as a current-gain device, required a different design philosophy that old-school engineers were reluctant to adopt.

In February 1950 *Electronics* noted that "tubeless devices are already appearing on the horizon at a rapidly increasing rate, and it is already apparent that people in this business must broaden their thinking to include such devices. . . . The tendency of designers in the future will be to use tubes where only tubes can do the job, or where tubes do the job best."

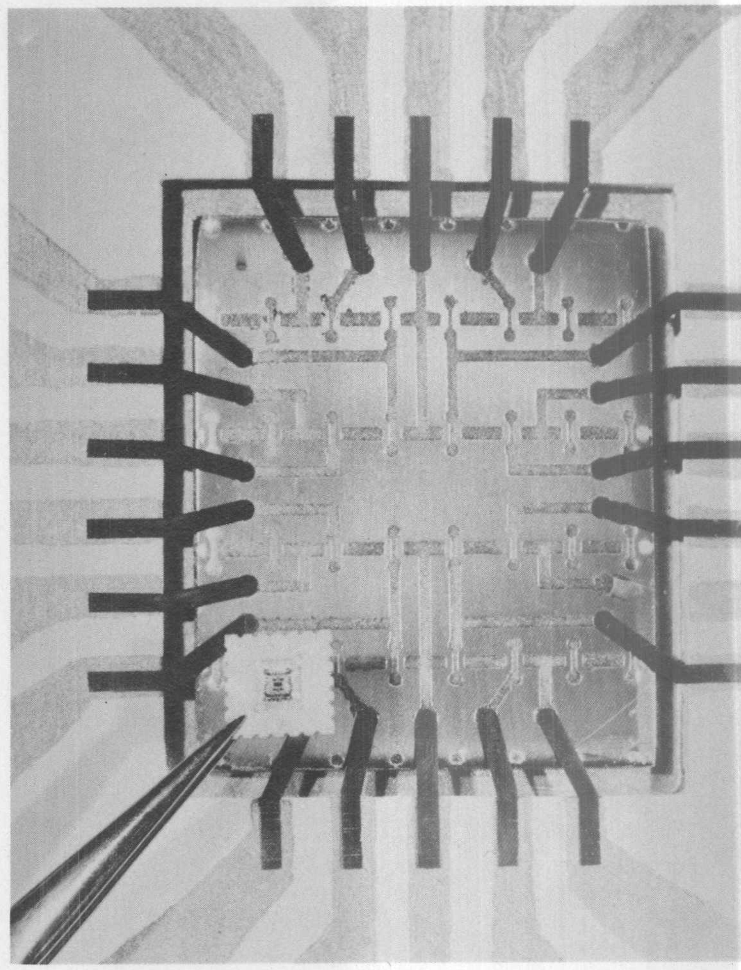
Exactly three years later the message in *Electronics* reflected a new awareness of the role of the transistor: "As we enter the age of transistors, it is important that engineers open their eyes wide to the potentialities of these new devices that are like tubes and yet are not like tubes. Circuits can be developed by thinking of transistors as substitutes for tubes. But more important circuits will come in the harnessing of characteristics that are peculiar to transistors themselves."

Because of the premium prices at which they entered the market, transistors were slated at first for places where tubes could not fit. The military, already hotly pursuing miniaturization and virtually unconstrained by prices, bought batches of the first transistors from companies like Raytheon, General Electric, and Western Electric. But even at the market's other extreme—consumer products, where cost is the primary concern—a demand for transistors arose. Transistorized entertainment equipment may still have been a few years off, but another consumer product picked up on the transistor from the start: hearing aids.

There, manufacturers were on a continuing campaign to reduce the size, weight, and battery requirements of the product well before transistors had come on the scene. It was a market that could absorb the premium cost of the devices, which sold in the early fifties for about $15 each.

The first transistorized hearing aid was announced by Sonotone in February 1953. It used five transistors, but still required a pair of miniaturized tubes for the input and driver stages, since solid-state devices were still too noisy and lacking in drive capability.

While point-contact transistors were being improved, scientists at Bell were perfecting crystal-growing techniques. Gordon Teal and J. B. Little as early as the fall of 1948 had successfully produced single crystals of germanium by slowly pulling ingots from the melt. But techniques for doping the germanium accurately and uniformly eluded Teal for more than a year. Moreover, during all that time he faced opposition from other researchers at Bell, who argued that single crystals were not only unaffordable for production, but also unnecessary. Teal carried on.



Early MOS. The close-up of the ceramic-packaged metal-oxide-semiconductor chip (held by tweezers) is actually a mockup, but it shows the details of the metal interconnecting 16 MOS transistors in this logic circuit from RCA. The year was 1963.

By 1950 he was able to adapt his crystal-pulling apparatus to accept pellets of impurity materials. This finally made possible the device that Shockley had envisioned years before: the junction transistor. By changing the impurity during the pulling of a p-type ingot to make a thin layer of n-type germanium, then reverting back to the impurity for p-type conductivity, Bell Laboratories produced a crystal that could be sliced into many pnp bars. Wires attached to each of the three regions completed the grown-junction transistor, which was far less noisy and could handle significantly more power than its point-contact predecessor.

By this point, industry interest was thoroughly aroused. In March 1952 a meeting of the Institute of Radio Engineers on transistors had to be repeated to accommodate overflow crowds. That September the number of transistor licensees under Western Electric patents totaled 26 domestic and 9 foreign. Transistor technology was finally moving.

The U. S. military contributed significantly to the

MOS man. Although field-effect transistors were in production at the time, in 1963 Steven Hofstein of RCA developed a form of insulated-gate FET suitable for integrated circuits. Working with Frederic P. Heiman, Hofstein produced the circuit shown projected to his right.

advance through major contracts that boosted production volumes. In October 1952 over $5 million in military contracts were signed with four of the major independent suppliers of semiconductor devices—Raytheon, General Electric, Sylvania, and RCA. The contracts called for weekly deliveries of over 5,000 units each of point-contact and junction transistors and germanium diodes.

By the end of 1952, point-contact transistors were oscillating at over 300 megahertz, Raytheon had announced the mass availability of junction transistors, Cornell University had introduced a course on the subject, and the devices were cropping up in equipment everywhere.

That the transistor signaled a new era of design was made clear by an RCA radio output stage. It provided 500 milliwatts to its directly coupled speaker. The circuit hooked pnp and npn transistors together in a "complementary symmetry" arrangement—for which no vacuum-tube analog existed. Demand for the new devices spurted so fast in 1952 that manufacturers began to seek ways to automate production. And major technological developments were reported outside of Bell Laboratories. General Electric developed a technique for building junction transistors by alloying indium pellets to opposite sides of a thin piece of germanium. The device was called an alloy-junction transistor, and it was later produced in volume by RCA and Raytheon.

An improvement in the alloy process came in 1953 when Philco developed a technique for electrolytically jet-etching the germanium thickness at the point where the indium pellets were to be alloyed. Nozzles directed a spray of indium sulphate at either side of the germanium, while the slice was held at a positive potential. An infrared sensor detected when the semiconductor had been etched to the proper degree, as low as 0.2 mil, and shut off the process. Reversing the potential on the germanium then plated indium into the depressions. Philco's so-called surface-barrier transistor achieved the highest frequency of operation for a junction transistor—100 MHz.

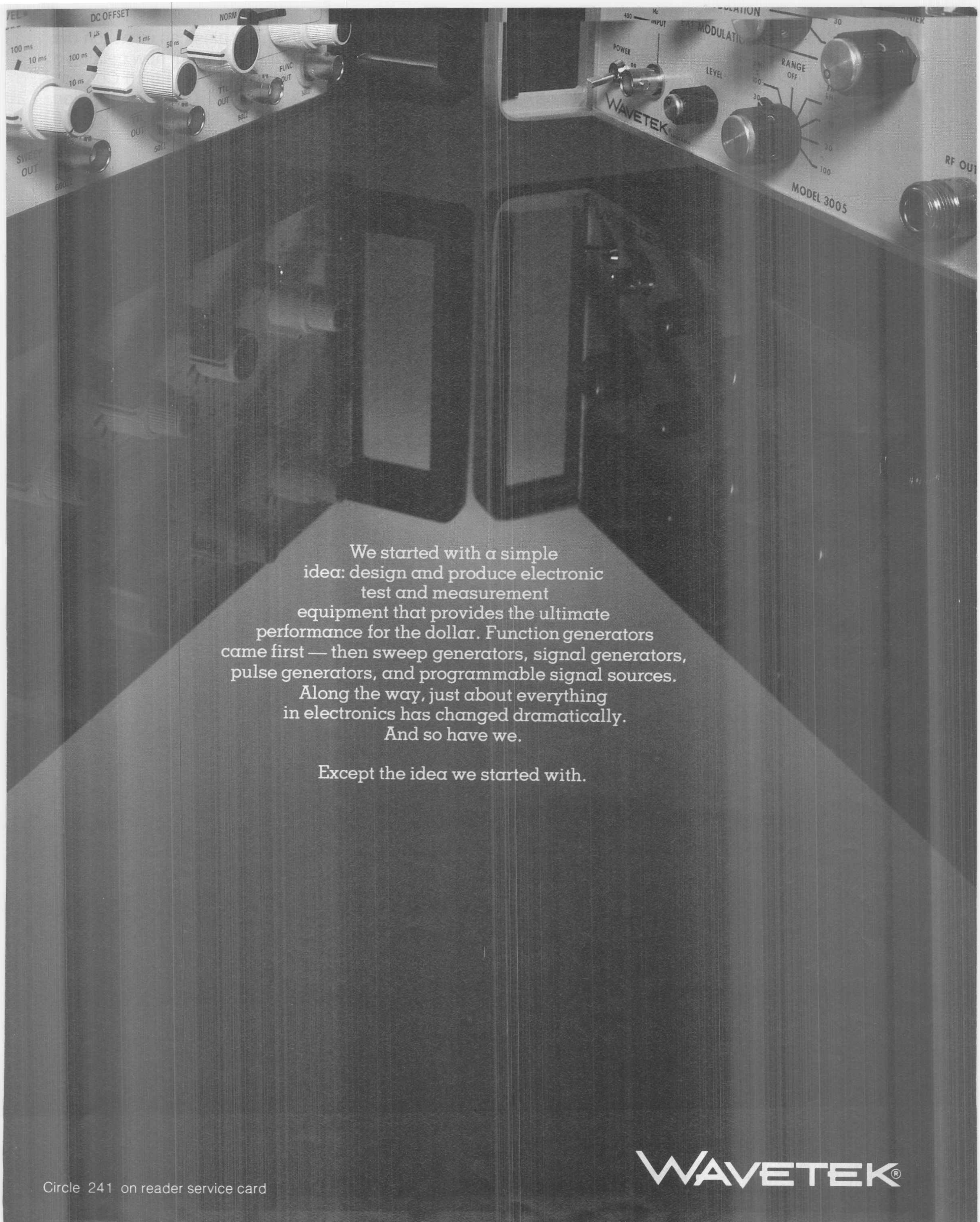
A concern for transistor standards also began to emerge by 1953. Device manufacturers had to proceed cautiously in the introduction of new products for general use, because there was widespread confusion about what constituted a good transistor. Physical standards—lead spacing, package shapes, and so on—were established in early 1953. In mid-year, through the initiative of the Army Signal Corps in collaboration with the Navy, the Air Force, and representatives of leading manufacturers, standards for the operating characteristics of transistors were proposed.

All through the fifties most manufacturers of transistors were focusing their research on improving the devices and improving assembly techniques. One development came in 1953 from engineers at General Electric's Advanced Semiconductor Laboratory in Syracuse, N. Y. While experimenting with germanium alloy tetrodes—actually double-base transistors—researchers who were trying to come up with a device that would operate at higher frequencies stumbled upon an oscillatory signal that led to the unijunction transistor. The device, which was at first called a double-base diode, exhibited a negative resistance that could be put to use in relaxation oscillator circuits.

Other device developments stemmed from fundamental semiconductor research. One was the controlled silicon rectifier, developed at GE's rectifier engineering laboratory in 1957. It was a silicon rectifier whose forward current could be blocked under control of a gate electrode, and it had great potential as a high-power ac switch. The device, known today as the silicon controlled rectifier, or SCR, relied on a four-layer (pnpn) structure with a high impedance. It could be made to avalanche by a current injected into its internal n layer.

Another such case was the commercial development finally of the field-effect device conceived by Lilienfeld some 30 years before. In 1958 Stanislas Teszner, a Polish scientist employed by CFTH, an affiliate of General Electric Co. in France, created the first junction field-effect transistor. Called the Tecnitron, it was a germanium alloy device without an insulated gate. It operated into the megahertz region. Crystalonics, a division of Teledyne Inc. in Cambridge, Mass., produced the first domestic commercial JFETs in 1960.

Perhaps the most classic case of pure research result-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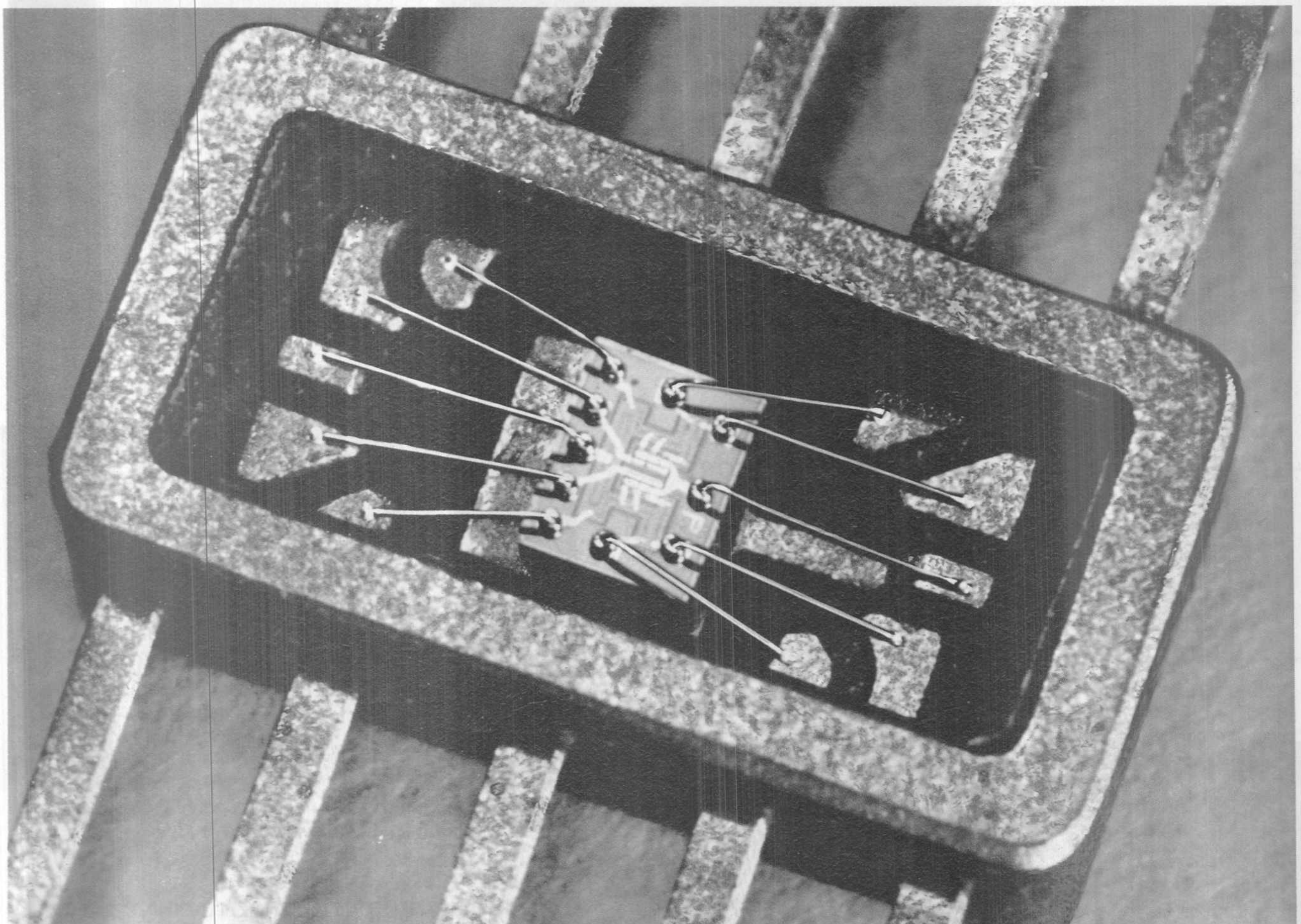

Apollo chip. One of the early bipolar integrated circuits, this chip—a three-input NOR gate using resistor-transistor logic (RTL)—was built by Philco-Ford for MIT Lincoln Labs. It emphasized reliability—a backup computer for an Apollo program launch was built entirely of these chips.

ing in a semiconductor device was the development of the tunnel diode. Its feasibility had been been predicted in essence in 1929 by George Gamow and two others, all of whom independently suggested that because of the wave nature of matter, particles of a given potential would probably be capable of penetrating barriers of higher potential.

Then, in 1958, Leo Esaki, a Japanese scientist with the Sony Corp. in Japan, shook the semiconductor world with his development of the tunnel diode. It was so named because its operation relied on the quantum-mechanical probability of electrons tunneling through an energy barrier they could not surmount. Esaki formed an extremely abrupt junction between very highly doped p and n regions of germanium to make the depletion region of his diode very thin—on the order of a few hundred angstroms.

Application of a forward bias to such a diode increases the net tunneling current in the forward direction. Beyond a certain bias, however, fewer and fewer states for tunneling are available, and forward current decreases with increasing bias. That behavior corresponds in effect to a negative resistance, which can be put to use for high-frequency amplification, oscillation, or switching.

By mid-1959 RCA had developed experimental tunnel diodes that operated at frequencies in excess of 1 gigahertz, and it predicted that the devices would be used in computers for memory elements "whose operating limits were only imposed by the speed of light." GE reported devices that switched in 100 picoseconds, and the company saw a great future for the diode. In a tribute to its importance, Esaki received a leave of absence from Sony in February 1960 to pursue research at IBM's laboratory in Poughkeepsie, N. Y., as a resident consultant.

Then interest in the tunnel diode waned rapidly. Several reasons were cited in the early 1960s. One was that transistors had improved significantly in high-speed switching characteristics, and their prices had fallen swiftly as batch processes made tremendous volumes available. *Electronics* reported that epitaxially grown semiconductor devices had replaced tunnel diodes as the glamour product at the 1960 International Electron Devices Meeting. Ultimately its death knell was sounded by the integrated circuit, which was to become the heart of computers and computer memory—an area targeted for the Esaki diode.

Gaining in importance throughout the late fifties and early sixties were semiconductor devices whose operation extended to the uppermost frequencies—millimeter waves—and beyond to the visible-light spectrum. Most of these emerged from compound semiconductors, such as gallium arsenide and indium phosphide. As early as 1955 physicist R. Braunstein had observed infrared

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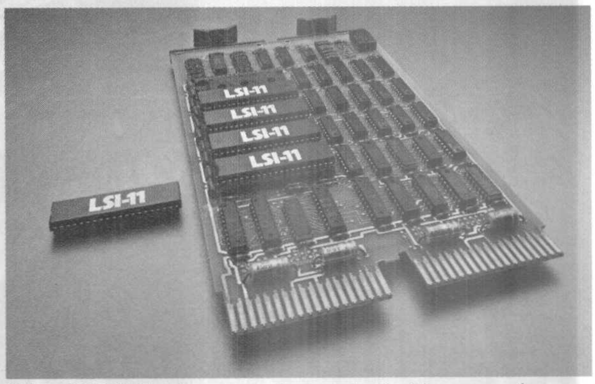

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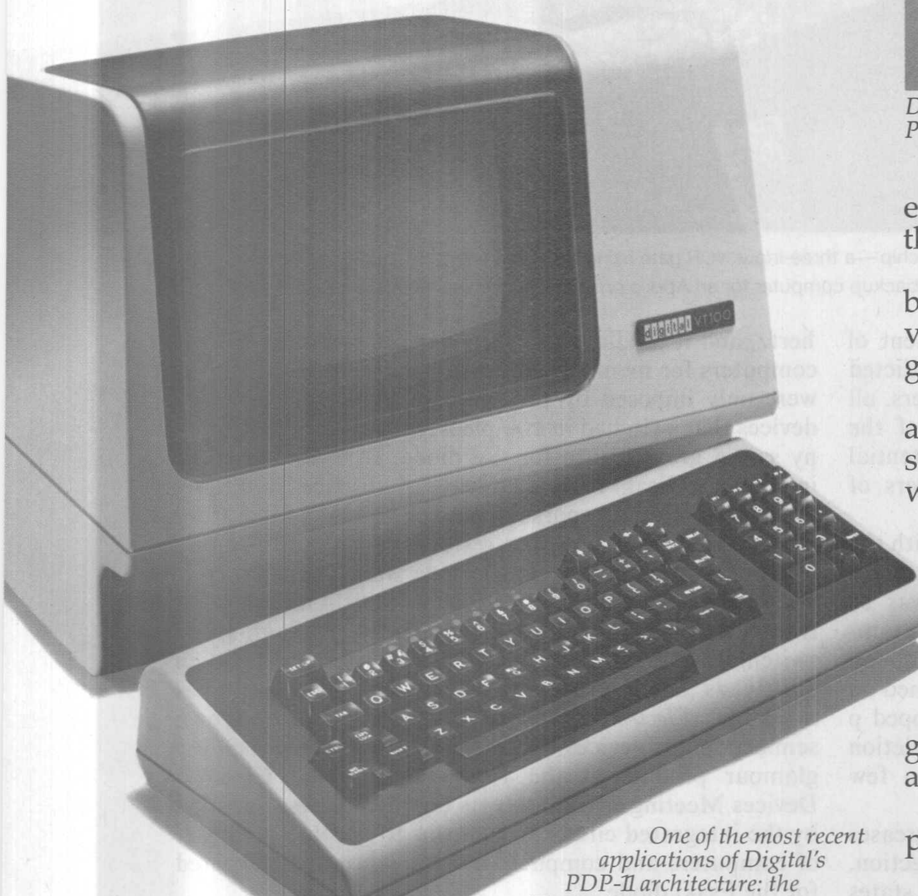

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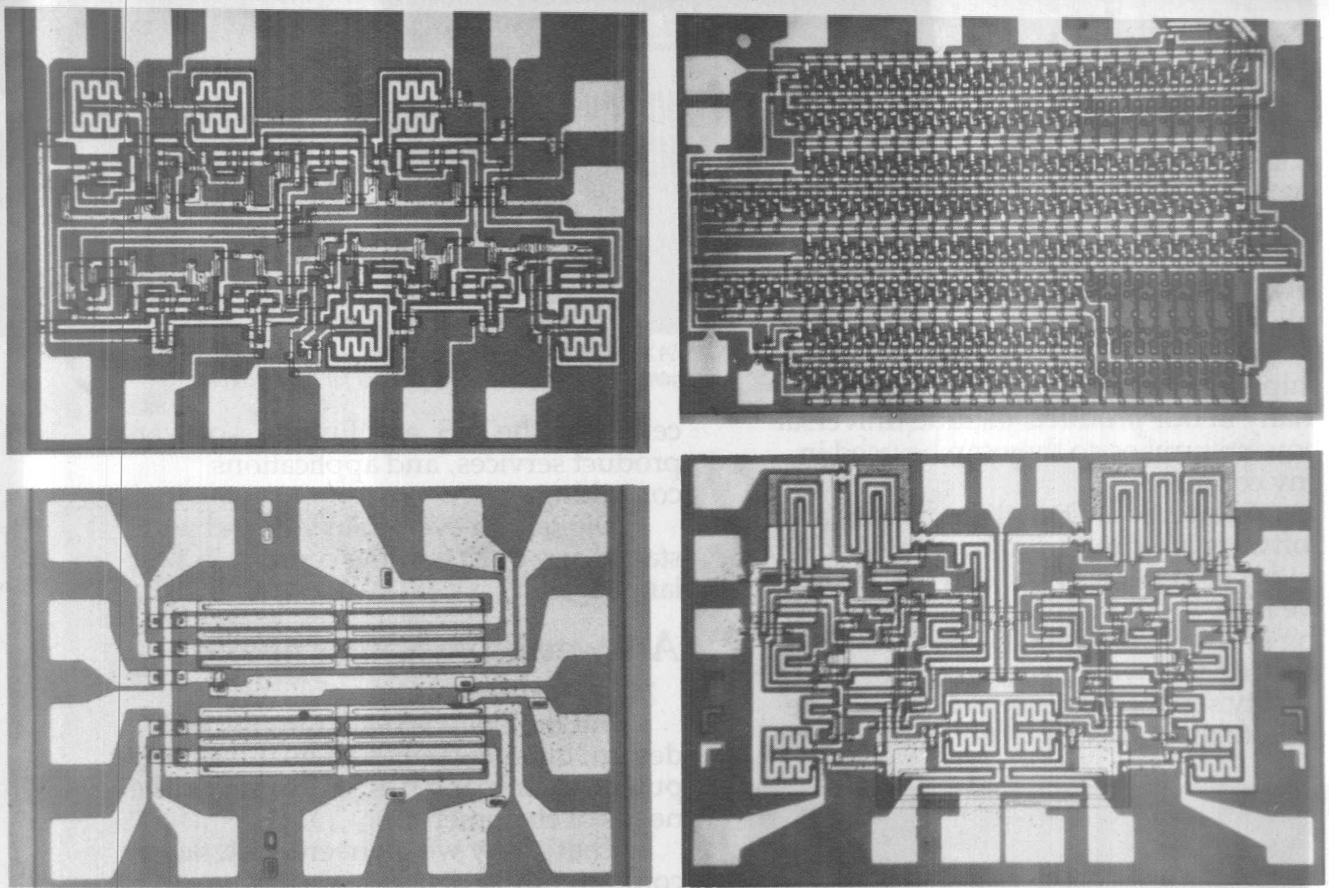

Chip set. Shown are four of the 29 MOS chips General Microelectronics built for the Victor Comptometer Corp. in 1964. Top left is a BCD-to-binary converter, top right a dual 20-bit shift register. Below left is a dual four-input gate, and below right a dual J-K flip-flop.

radiation produced by carrier injection in gallium antimonide, gallium arsenide, and indium phosphide semiconductors. He surmised then that the radiation was due to the direct recombination of electron-hole pairs. But it was not until 1960, when British physicists J. W. Allen and P. E. Gibbons built point-contact gallium phosphide light-emitting diodes (LEDs), that a wide spectrum of visible light was produced.

When it was discovered in 1958 that the principle of masers—microwave amplification by stimulated emission of radiation—could be applied to visible light, interest was aroused in the idea of producing laser action with semiconductor junctions. Not until 1962, however, was coherent infrared radiation observed from forward-biased gallium arsenide pn junctions at Bell Labs.

In the early sixties the microwave field also became aware of semiconductors, both for generating the signals and detecting them. This was because of developments like the Gunn diode—named after its inventor, J. B. Gunn, who in 1963 observed oscillations in compound semiconductors under an applied electric field. Another significant device was the Impatt diode—developed by two Bell scientists, R. L. Johnston and B. C. DeLoach, who coined the name for their microwave-generating impact avalanche transit time diode in 1964.

Although nearly all the early manufacturers of transistors were well-established makers of tubes—including Raytheon, Philco, General Electric, RCA, and Sylvania—that was no assurance that any company would be successful in the semiconductor business. Many newcomers, relying on perseverance and ingenuity, quickly built sales that rivaled those of the largest corporations. One company, Transitron, set up shop in an old bakery in Melrose, Mass., and by the mid-fifties grew to become the second largest manufacturer of semiconductors.

A classic case of a successful latecomer to the transistor business was a Dallas-based manufacturer of geophysical instrumentation apparatus: Texas Instruments Inc. After procuring its transistor manufacturing license from Bell in 1952, TI turned swiftly to production by forming a semiconductor laboratory in 1953. It was headed by Gordon Teal, who had left Bell. The TI laboratory produced point-contact transistors as well as junction transistors later that year, but it made its most significant contribution in 1954, when it announced the first transistor made of silicon.

Silicon, with its 1,420°C melting point, could build transistors that had a much wider operating temperature range than germanium—and that was of utmost importance to the military. Moreover, since the silicon grown-junction transistor could tolerate the excessive temperatures produced by large currents, it could handle more power than a germanium one. By resorting to the grown-junction technique, TI had succeeded in producing a

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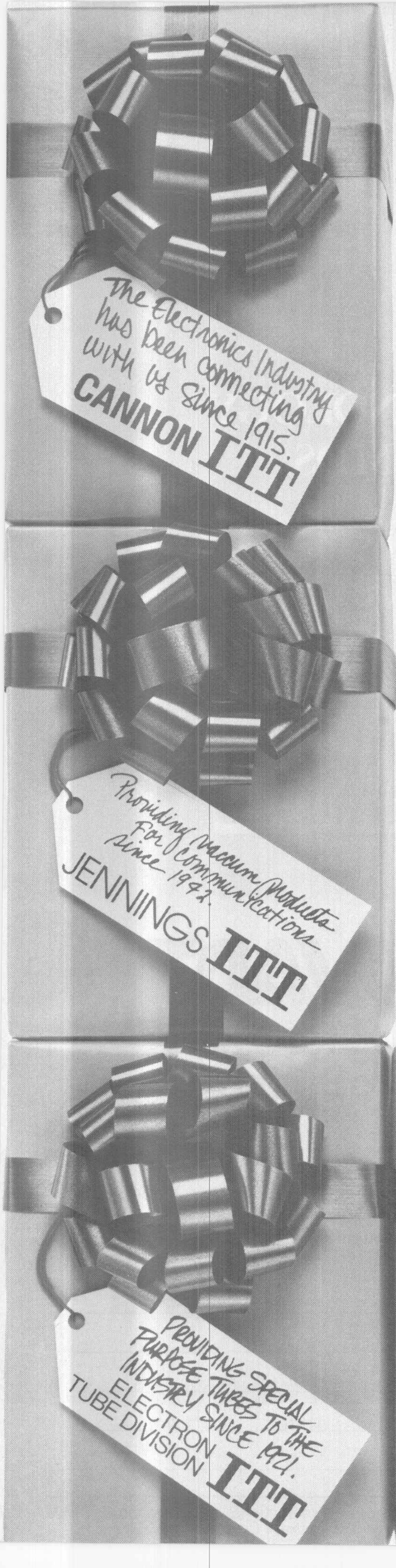

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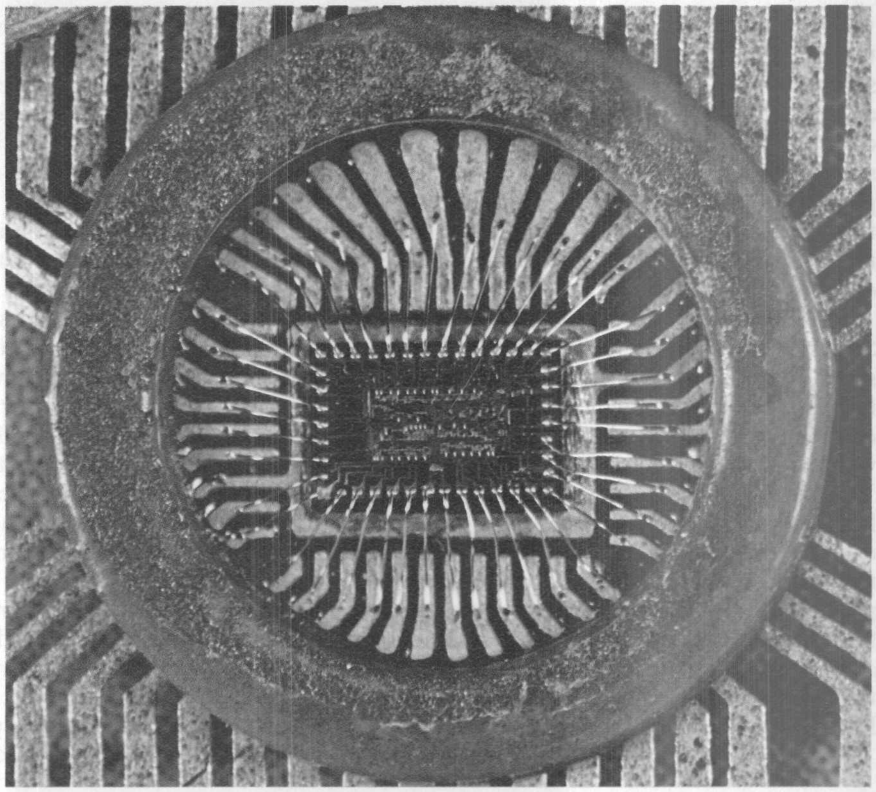


Round flatpack. The MOS integrated circuit's capacity for denser ICs than bipolar devices brought about this packaging scheme in 1965. The chip, a custom circuit for the military, integrated 968 components in the 44-pin package.

silicon device of good quality when many engineers in industry thought that its fabrication lay years beyond the then current techniques.

TI's hastening of the silicon transistor into production gave it a three-year jump in that market segment. And it proved that in the exciting new semiconductor industry nearly any energetic company could outpower the established manufacturers and secure a market niche in a surprisingly short time.

With production processes that were not just different from conventional manufacturing techniques but in many respects bordered on alchemy, semiconductor makers sought the brilliant young physicists and other scientists needed to advance the state of the art. This soon created a rash of job-hopping. Some scientists who had trained in large, established companies abandoned them for more exciting, even risky, opportunities. Among them was William Shockley, who left Bell Telephone Laboratories in 1954 to start his own company. His co-inventors Bardeen and Brattain stayed on with Bell Laboratories to continue basic research—Bardeen became the recipient of a second Nobel Prize for his work on superconductors.

It was mainly the reputation of its founder that enabled the Shockley Semiconductor Laboratory to attract some of the best talent in the industry to Palo Alto, Calif. Though the enterprise lacked business direction and ultimately faltered, it was the seed from which the entire Santa Clara area semiconductor industry—Silicon Valley—sprang, for Shockley excelled in picking able young men whose leadership qualities would be proved in later endeavors.

After approaching several potential backers—including Raytheon and even the Rockefellers—Shockley succeeded in setting up his company as a subsidiary of Beckman Instruments. The next step was to staff it, and Shockley did so with, among others, Eugene Kliner, Jay Last, Victor Grinich, Jean Hoerni, Sheldon Roberts, Julius Blank, Gordon E. Moore, and Robert N. Noyce. Those eight—all in their twenties, all from established electronics companies in the East, and all noted in their professions—were to abandon Shockley later to found Fairchild Semiconductor and make semiconductors their own way.

It came as no surprise to knowledgeable observers in the industry that the eight became disgruntled and left after only two years, for they were never certain under Shockley's leadership just what their business was. Although Shockley Semiconductor was a manufacturing concern, its atmosphere was more that of a laboratory at a university. Shockley was good at generating innovative ideas, they said, but unable to focus on a product line. He eventually sought to develop a new device, a four-layer avalanche diode, but by that time many at the company had made up their minds to leave. Once they did—in 1957—Shockley's company lost its lifeblood. In 1958 he changed its name to Shockley Transistor Laboratories, to emphasize manufacturing, but in 1959 the company was bought by Clevite, which itself was bought by ITT in 1965. ITT closed the Palo Alto plant in 1969.

The "traitorous eight"—as Shockley came to call them—had managed to get in touch with John Carter, then president of the Fairchild Camera and Instrument Corp. He agreed to finance them as a separate venture, but reserved an option to buy the operation in two years. With funds secure, the eight men—plus Murray Siegel, an electrical engineer who had journeyed cross-country to Shockley but joined the new outfit instead—set up

their facilities in Palo Alto. By mid-September 1957 they had their work cut out for them. Siegel took responsibility for the applications laboratory with Grinich, also an electrical engineer, who would define and specify device characteristics. Roberts had the job of growing silicon crystals. Noyce and Last were in charge of the photoetching techniques. Moore and Hoerni contributed the diffusion expertise. Kliner was the administrator, responsible for running the business side of the new company.

Fairchild's first product was one that it thought Shockley should have focused on: the diffused-base transistor, based on the mesa process. Fairchild could not have made a better choice; the transistor-building process that was to have the most far-reaching implications was based on diffusion.

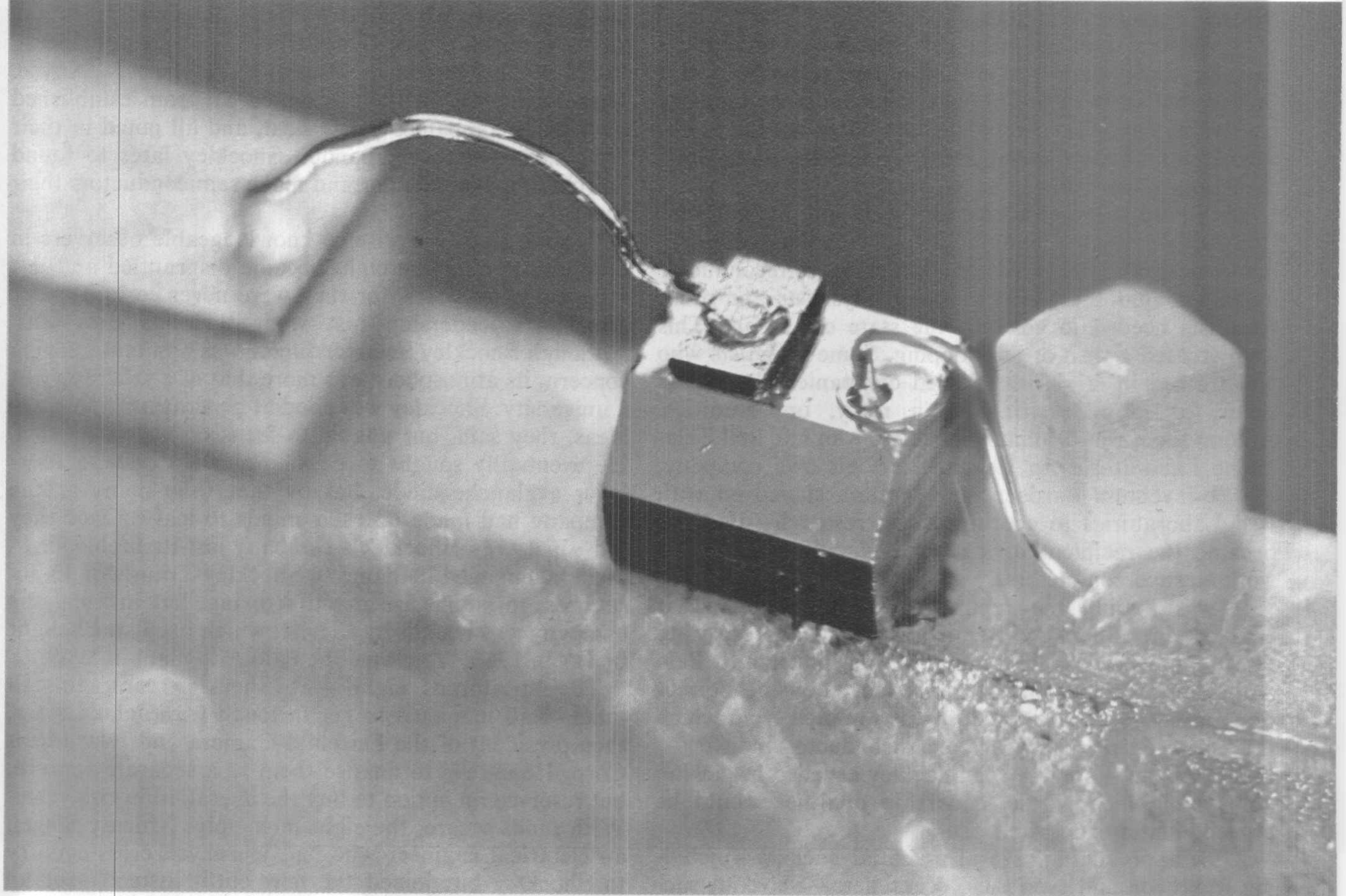
Diffusion offered the immediate advantage over earlier transistor-making processes of tremendous control over the thickness of the base region: because the impurities entered the semiconductor to a depth accurately predictable from temperature, vapor pressure, and time, base thickness could be controlled some 10 times more accurately than with previous methods. Another advantage, not so immediately apparent, was that diffusion lent itself to batch processing of transistors.

The first device built by diffusion was the mesa transistor, named for the flat-topped mountain its cross section suggested. The mesa could operate at higher frequencies than earlier devices—some of the first mesas reached the gigahertz level—and it was more rugged and better able to dissipate heat because of its structure. The device first made its appearance in 1958, and by 1959 it seemed to be the last word in transistors. It was then, however, that Fairchild Semiconductor made its mark in the transistor industry with the planar process.

Though it still relied on diffusion and masking steps, the planar process made several improvements on the mesa process. The mesa transistor was in production at the time and selling well, but it was relatively fragile and still subject to surface contamination. In focusing on the latter drawback, Fairchild intended to figure out a way to passivate the transistor. Silicon dioxide, which had become the conventional mask in the diffusion process, would not serve as a passivator because certain impurities would in time diffuse through it to the junction below and cause failure. This Bell Laboratories knew well. It was Fairchild's Hoerni, a physicist with two doctorates, who discovered that doping the oxide with impurities would render it an effective passivator.

Passivation of the semiconductor surface was just one advantage of the planar process. Leaving the oxide covering the transistor strengthened the delicate junctions;

Laser diode. In announcing this laser diode chip (dwarfed by the grain of salt at the right), Bell Labs promised that phone conversations would be carried over a beam of light. The gallium arsenide device was developed after the solid-state maser in the late sixties.



now a less brittle, more reliable device was possible. But Hoerni's process had another significant advantage: as its name implies, the planar process was flat. Rather than mounting the base layer on top of the collector substrate, Hoerni diffused it down into the collector. That not only made the structure less delicate, but also allowed interconnection to the transistor's three regions to be made by metal lines evaporated onto the oxide—rather than by painstakingly hand-attached wires.

Fairchild's new process moved to commercial production in less than a year, though it was not announced until 1960 and the secret of its workings was not revealed for several years. Hugely successful from the start, the planar process nevertheless had a drawback: the inability to produce power transistors, because of the high resistance of the collector material. But that problem was soon to be overcome.

In June 1960 Bell Telephone Laboratories announced a new, epitaxial method of fabricating transistors—the growing of a thin silicon layer on a single-crystal substrate. Since the resistivity of the layer could differ from that of the substrate, the process allowed the formation of transistors within the epitaxial layer whose characteristics were independent of the substrate material. That meant that transistors with a thin base (high frequency) and low collector resistivity (high power) could be built on a strong, thick substrate.

Though not unique to the semiconductor industry, one concept that was to become almost a cliche was the learning curve. That an increase in production volume—and hence manufacturing experience with a product—could lower its cost was well known. Not only had components like resistors, capacitors, and vacuum tubes slid down the cost curve, but products in other industries routinely also did so. However, in no business was the curve so steep as in the semiconductor industry.

While all these advances seemed by mid-1960 to forecast an unending boom in the semiconductor business, rapidly escalating production saturated the market—not because applications were lacking, but simply because buyers were unable to use the devices as fast as they were being turned out.

The assembly of electronic equipment was a laborious, time-consuming process, slowed even further by the increasing complexity of the circuits. The sheer numbers of switching devices in digital equipment—computers in particular—had risen astronomically. Control Data Corp.'s CD 1604 computer, introduced in 1960, for example, comprised some 100,000 diodes and 25,000 transistors. The demand for the functions existed, but not the means to speed building the end equipment.

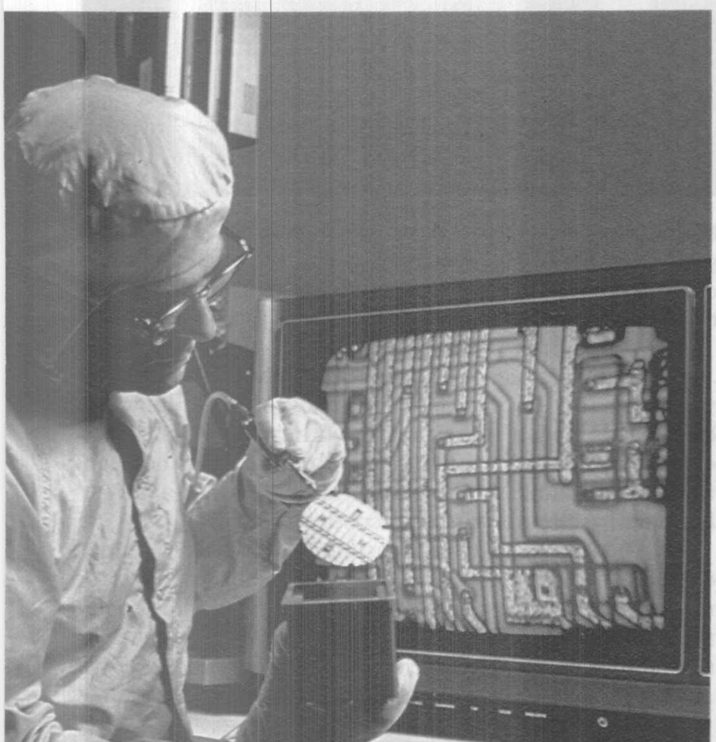
The stage was set for a new technology, one that could accommodate the increasing complexity of circuits by eliminating the interconnections of discrete parts. The integrated circuit was bound to be invented.

So pressing was the need for fabricating entire circuits in a single semiconductor block that had neither Jack Kilby nor Robert Noyce conceived of the integrated circuit in 1959, someone else surely would have. The mesa and the planar transistor had both lent themselves to batch processing, in which many transistors on a single wafer are diffused and etched at once. Doubtless more than one researcher had thought it senseless to cut them apart to be packaged, only to be reconnected later into a circuit. But the means for single fabrication had escaped the thinkers of the late fifties.

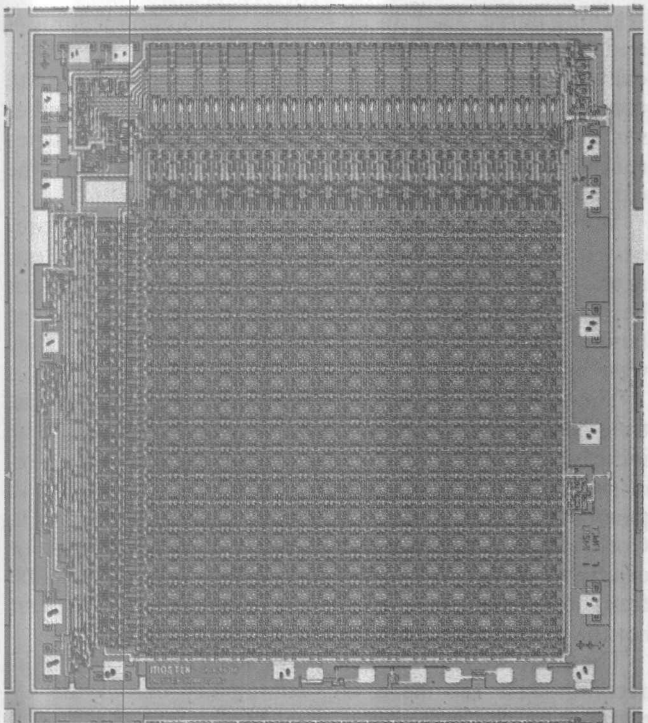
One scientist with an eye on the future, however, had proposed the integrated-circuit concept first in 1952, long before any batch processing of semiconductors even existed. Geoffrey William Arnold Dummer of Britain's Royal Radar Establishment at Malvern was delivering a paper on the reliability of radar components at the annual Electronic Components Conference in Washington, D. C. His statement, remembered only after the development of the IC, was incredibly prophetic:

"With the advent of the transistor and the work in semiconductors generally, it seems now possible to envisage electronic equipment in a solid block with no connecting wires. The block may consist of layers of insulating, conducting, rectifying and amplifying materials, the electrical functions being connected directly by cutting out areas of the various layers."

The two men independently credited with the inven-



Cleanliness. As semiconductor processing advanced, the clean room had to become cleaner still to prevent the occurrence of defects caused by dust. Class 100 became the byword—air with less than 100 parts per million of contaminants.



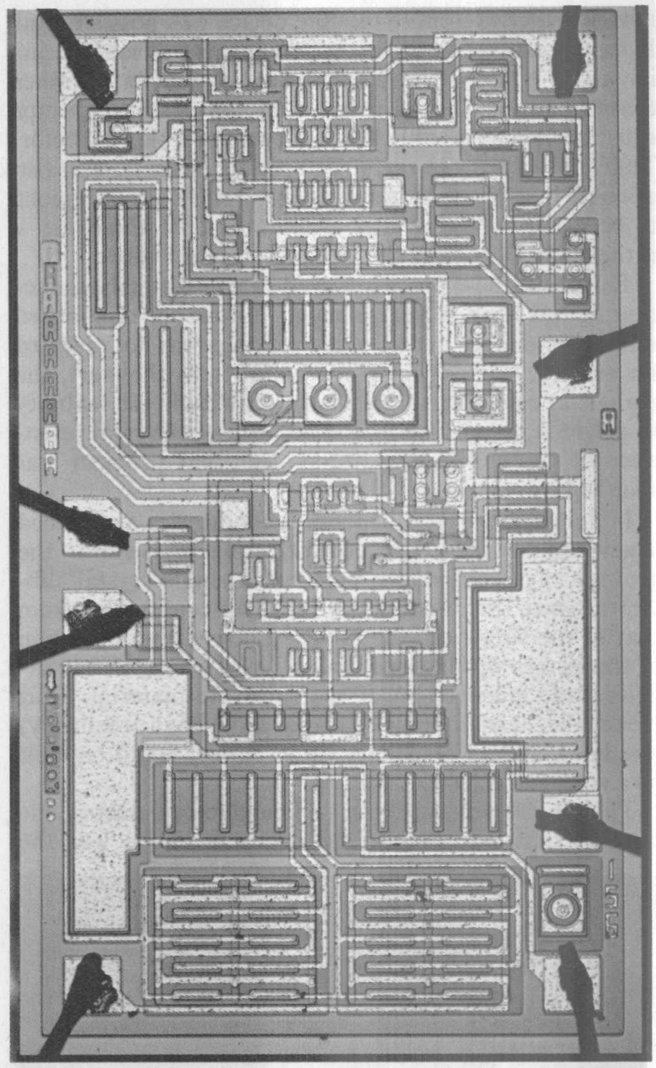
Implanted. One of MOS processing's greatest shots in the arm came with ion implantation, which was used first by Mostek in the production of this 1-K p-channel random-access memory, the MK4006. Doping the silicon by injecting ions allowed TTL compatibility.

tion of the integrated circuit, however, had neither heard Dummer's words nor even knew of him when their thinking began. They were simply scientists—Kirby at Texas Instruments and Noyce at Fairchild Semiconductor—who took the time to puzzle out a solution to a major problem in their industry: the skyrocketing costs of interconnecting discrete components into increasingly complex circuits.

Jack St. Clair Kilby had started his electronics career in 1947 as an engineer with Globe-Union's Centralab division, a radio parts manufacturer in Milwaukee. An extremely inventive man, Kilby was fascinated by Bell Telephone Laboratories' transistor and became hooked on transistor electronics when he attended the symposium Bell Labs gave in 1952 to its licensees, one of which was Centralab.

Kilby was put in charge of Centralab's hearing-aid development program, for which the company set up a small germanium transistor production facility. He was primarily responsible for the company's first tiny transistorized hearing aid, a project he oversaw until 1958. All during that time, however, Kilby's interest in the transistor grew more intense. He was frustrated because Centralab lacked the resources for semiconductor development, and he made up his mind to move on.

In May 1958 Kilby joined TI. His duties at first were not entirely clear, since he was to be working in the general area of microminiaturization. TI was at the time becoming involved with the Signal Corps' micromodule program, and Kilby felt that if he were to come up with a better circuit concept, he could avoid assignment to a micromodule proposal.



Mixing. By the seventies, linear circuit designs had expanded greatly, even allowing the mixing of field-effect and bipolar transistors on a chip. This operational amplifier from National Semiconductor, the LF156, was the first to use FETs for high input impedance.

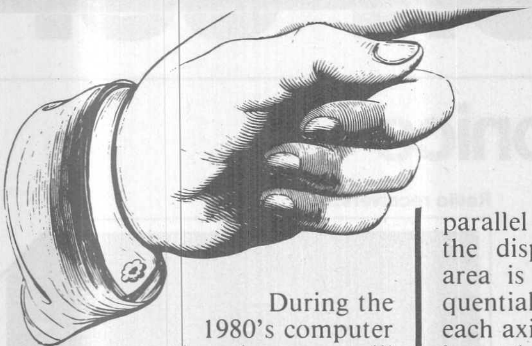
It was during one of TI's mass vacations—the first few weeks in July 1958—that the seed for the integrated circuit first began to germinate within Kilby. As a new employee, he was not yet entitled to vacation; he spent those weeks alone in the plant, thinking about a way to build entire circuits with semiconductors.

He knew it was already feasible to fabricate resistors, capacitors, and transistors from semiconductor materials. Resistors could make use of the ohmic property of bulk material, and capacitors were formed by reverse-biased pn junctions. His next step was to see if such junctions could possibly be fabricated from a single piece of silicon.

Kilby's bosses showed enthusiasm for his ideas, but they were also skeptical and needed proof that the circuits would work. So he set out to build circuits out of discrete semiconductor components. The first was a flip-flop that was built entirely of interconnected semiconductor devices.

TI had just begun at this time to develop diffused

TOUCH



During the 1980's computer based systems will continue to be introduced into virtually every area of our society, areas where potential users have little, if any, experience with computer systems. These systems should not demand that users become computer experts or learn typing skills and awkward command languages. Systems which demand these skills may invoke feelings of frustration, inadequacy, and hostility. Rather, the interaction should be at a level that respects the user's intelligence and knowledge. Carroll's **Touch** Input Systems offer a solution to this perplexing man/machine interface problem. By simply **touching** the display, the user selects a function in a confident and relaxed way . . . what is more natural than pointing?

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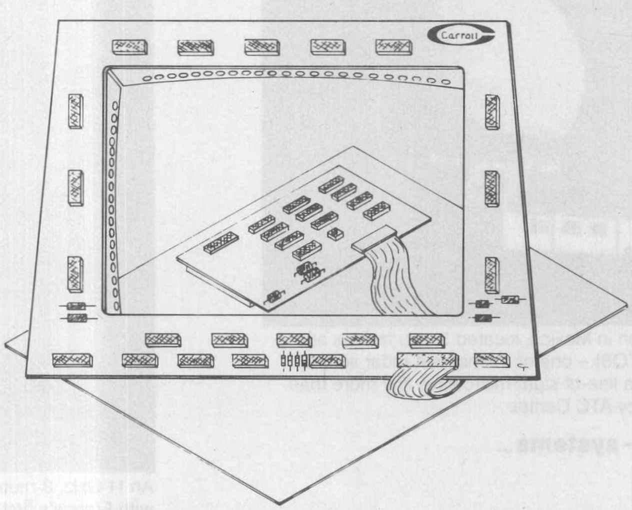
Touch Input has been successfully designed into a variety of applications including education, computer aided design, process control, interactive graphics, and personal computing systems. The medical profession has found **touch** advantageous in automating medical records, medical histories, and in radiology reporting systems. A major railroad system is specifying **Touch** Input as part of its track control system. The advantages of **touch** are now being recognized by government agencies which are specifying **touch** as a system requirement.



These application areas address a wide range of potential users: Elementary school students where reading and typing skills are limited . . . process control operators where fast and accurate interaction is critical . . . experienced users in applications (such as interactive graphics) where the interaction is complex and developing a command language is difficult . . . factory operators where the environment is hostile. Carroll's **Touch** Input Systems have accumulated millions of reliable operational hours in these application areas.

Touch has solved the man to machine problem because the user can interact confidently, accurately, and naturally without feeling frustrated or intimidated by a keyboard command language interface.

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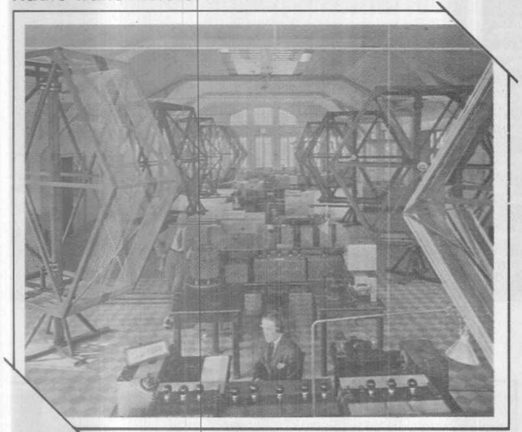

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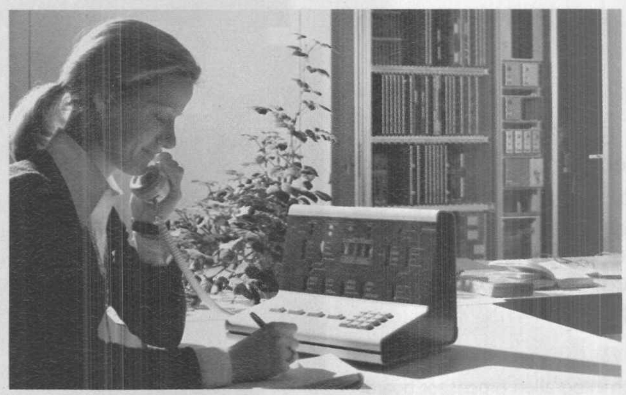

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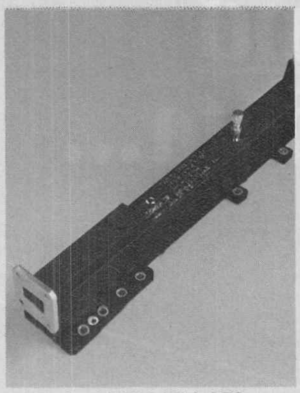

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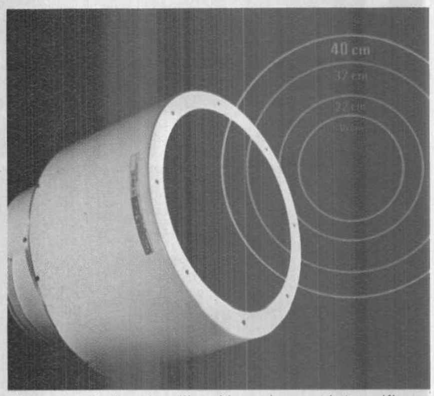

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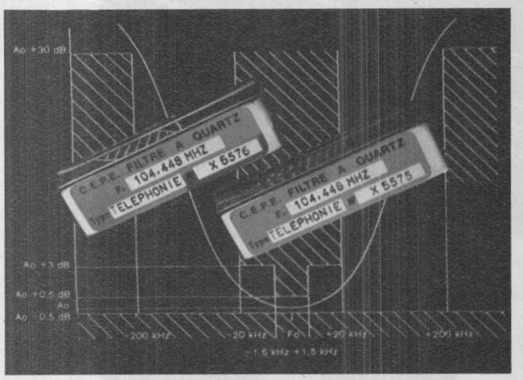

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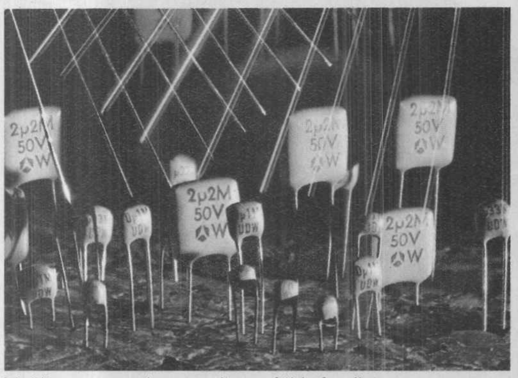

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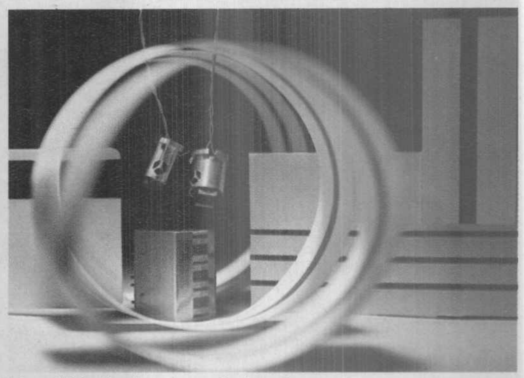

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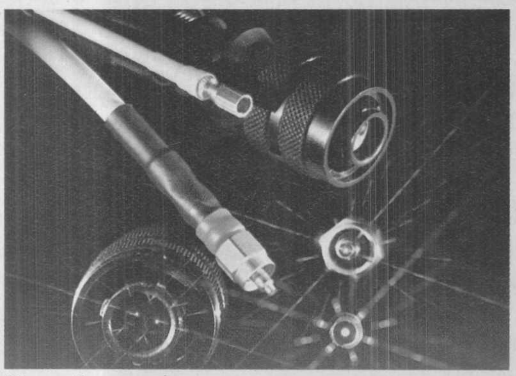

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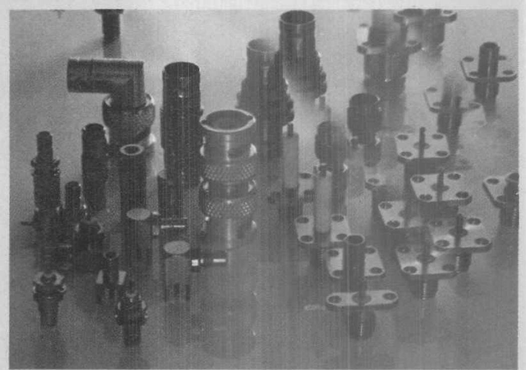

Coaxial connectors.

3839

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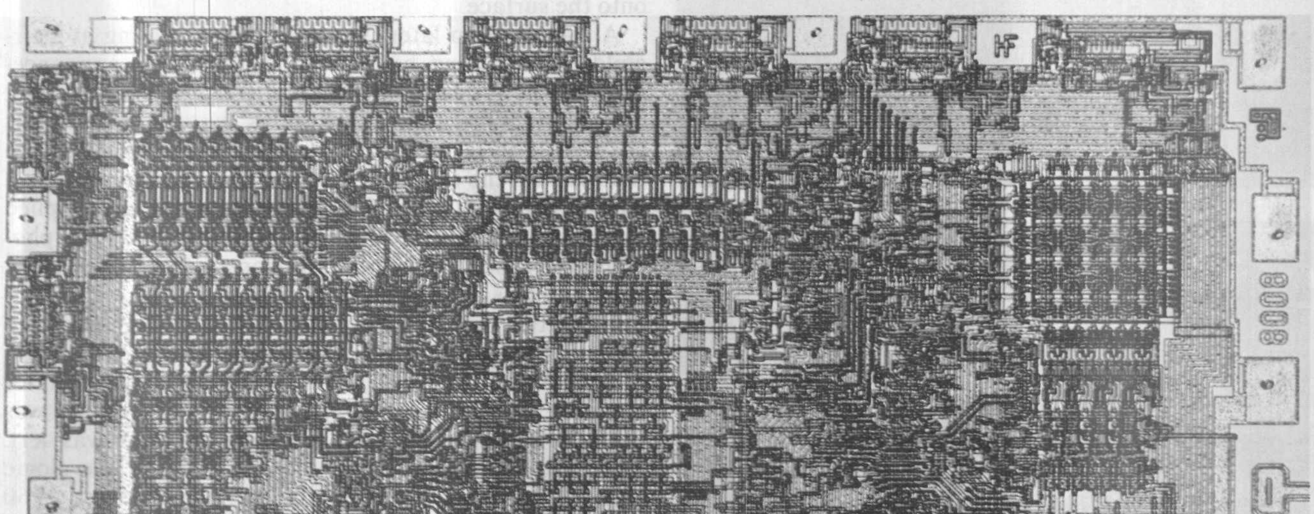
Founders. Intel Corp., founded by Andrew S. Grove (left), Robert N. Noyce (center), and Gordon E. Moore, was one of the most successful spinoffs from Fairchild. Intel was one of 13 semiconductor startups in the Santa Clara (or Silicon) Valley in 1968.

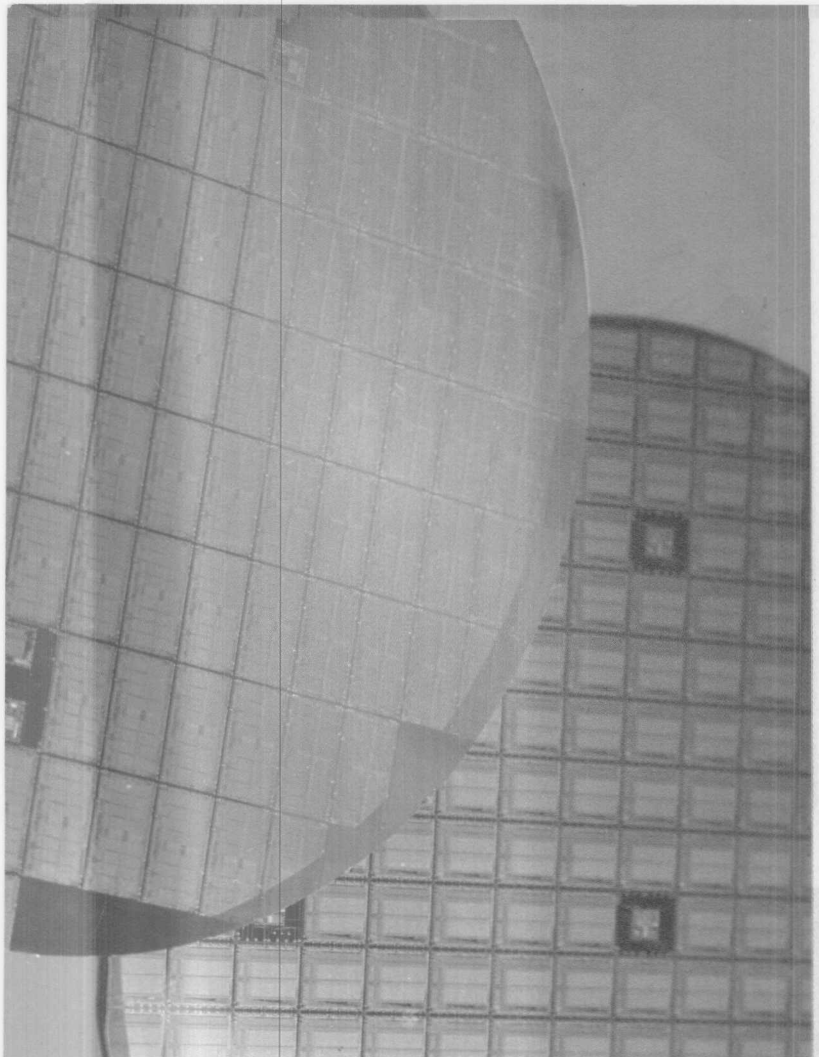
transistors—the only one it had in production was a small-signal germanium mesa device, fabricated 25 to a wafer. Kilby actually used the wafers as his breadboard for early integrated-circuit development.

He had a wafer cut up into a 1/16-by-3/8-inch bar to allow him a pair of diffused regions, and he made use of these and of existing contacts to build a phase-shift oscillator by interconnecting the elements with fine gold wires. One of the diffused regions was etched as usual after hand-masking to form the mesa transistor; the other became the distributed RC network to provide the phase shift. Kilby's integrated circuit worked, and he proceeded to build a flip-flop in a similar way.

Early in October 1958, he began design of a flip-flop to be built from scratch of monolithic germanium. It was to use bulk resistors, pn junction capacitors, and mesa transistors, fabricated simultaneously with photoetching techniques that TI had acquired. The device was completed early in 1959, and the "solid circuit" was unveiled at the Institute of Radio Engineers show in March,



8-bit microprocessor. The 8008, the first 8-bit microprocessor, established Intel as a leader in MOS circuit design. The p-channel silicon-gate chip integrated some 2,900 devices—a major step in integration in 1971—and executed 50,000 instructions per second.



dice per wafer—or yield. These wafers hold Texas Instruments' 4-K static RAMs, which got a boost in yield when fabrication equipment was converted from 3-inch to 4-inch wafers.

where Mark Shepherd, then a TI vice president, hailed it as "the most significant development by Texas Instruments since . . . the silicon transistor." By then, Kilby had applied for his patent.

Oddly, though the announcement was reported widely in the press, it was greeted with inordinate skepticism. Many of the criticisms were true: the constraints of integration meant that the performance of individual components of the circuit could not be optimized; the interconnection of devices made it difficult to manufacture the circuit (its yield, figured by the product of the yields of the individual devices, would be little better than 10%); and its designs were expensive and difficult if not impossible to change.

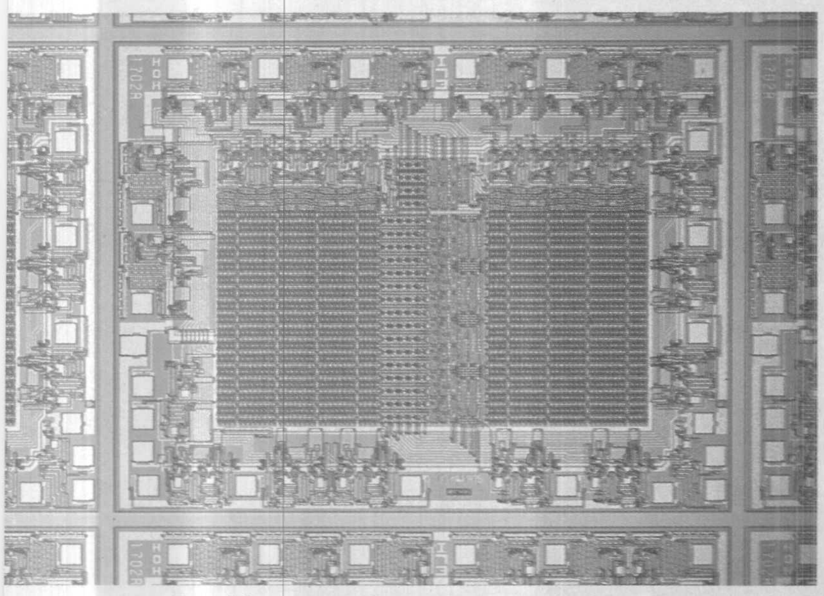
But many of the solid circuit's shortcomings were wiped out by the process of another semiconductor company. In January 1959 Robert N. Noyce, manager of research and development at Fairchild Semiconductor in Mountain View, Calif., was exploring the possibilities of the planar transistor, which Hoerni had developed the year before. He had entered in his notebook that month ideas about incorporating diffused or deposited resistors, about isolating devices from one another by means of reverse-biased pn junctions, and about interconnecting elements through holes in the oxide by evaporating metal onto the surface.

A month or so later Noyce called a meeting at Fairchild, after having heard of TI's impending announcement of the solid circuit. That meeting marked the first time that Noyce shared with his associates his ideas about putting several components on a single chip. From that day on, the evolution of the integrated circuit took a natural course at Fairchild. The patent had been applied for, and the process men worked closely with the photoetching experts to begin interconnecting diffused resistors and transistors on slabs of silicon.

Once the groundwork had been laid by Kilby and Noyce, the manufacture of integrated circuits commenced frantically in 1959. Fairchild hired as its circuit designer Robert Norman from Sperry. Norman was familiar with resistor-transistor logic, and it was RTL that Fairchild chose to implement in its Micrologic product line of integrated circuits. By February 1960 Fairchild announced that it was life-testing "large numbers" of its Micrologic family.

Texas Instruments had adopted Noyce's technique for evaporated metal interconnections and in March 1960 announced its first IC, a custom circuit for the military. By the end of 1961, both TI and Fairchild were producing commercial integrated circuits in production quantities—Fairchild its Micrologic and TI its series 51 logic family. In October of that year, TI delivered to the Air Force a small computer, complete with a few hundred bits of semiconductor memory, and announced its series 51^2 family, which used junction-isolated components and evaporated-metal interconnections.

Although only a few thousand integrated circuits were



Erasable memory. The first erasable programmable read-only memory was developed by Intel in 1972. The 1702, a 2-K device, relied on charge stored on oxide-embedded floating gates, which could be discharged under exposure to ultraviolet light.

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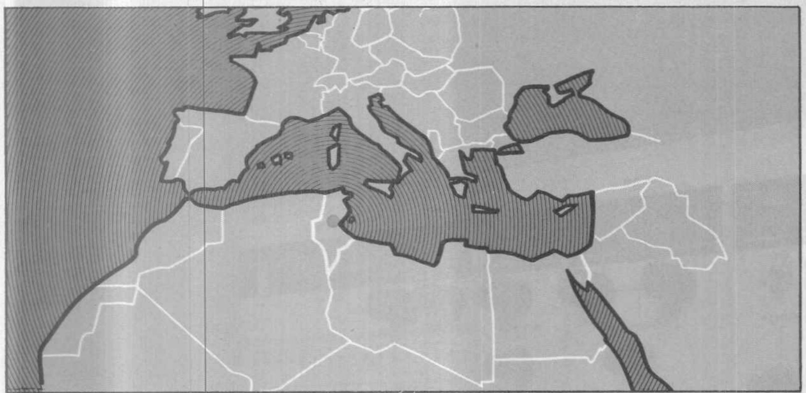

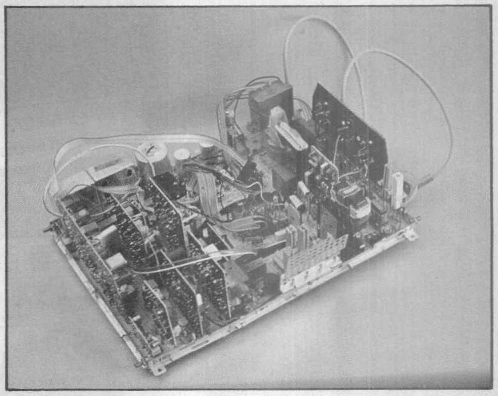

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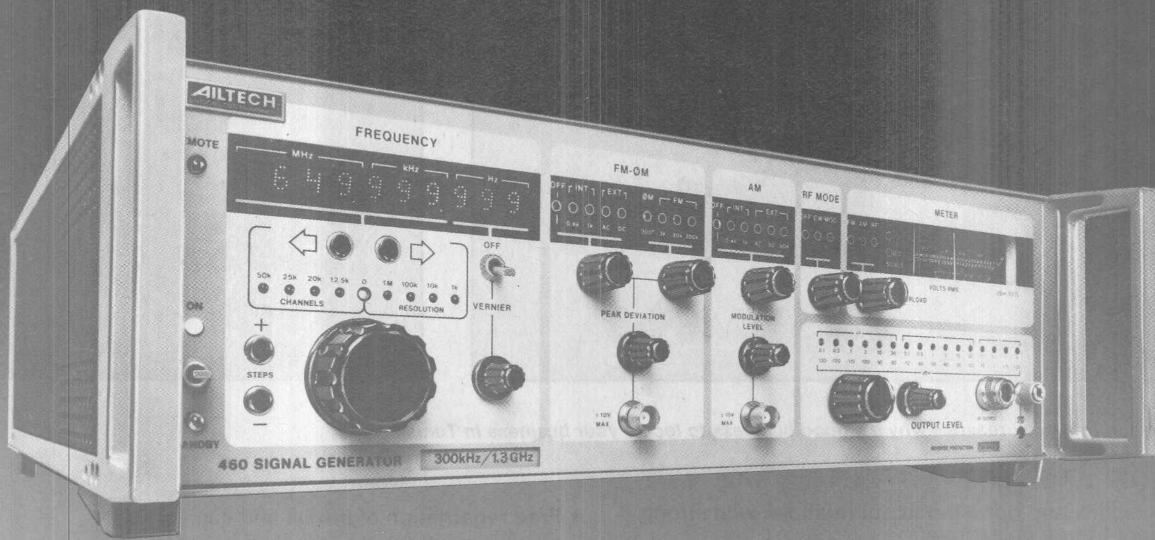

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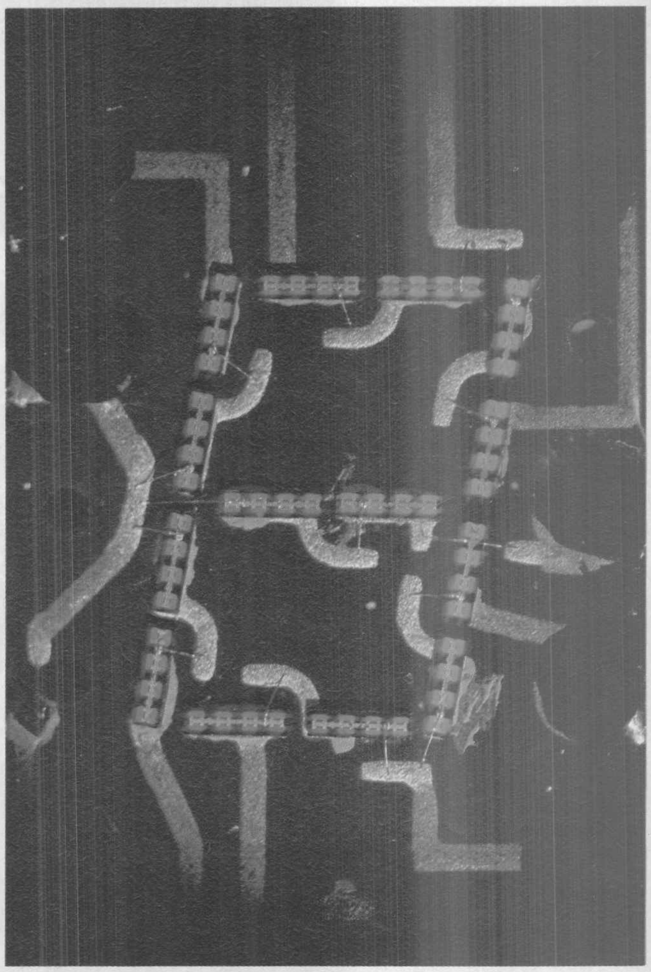
EATON Advanced Electronics

LED displays. Light-emitting diodes, developed in the early sixties, had been assembled into digital displays by the seventies. This seven-segment unit by Hewlett-Packard used gallium arsenide phosphide LEDs to build quarter-inch characters in 1971.



delivered in 1962, that year marked the beginning of mass IC production. TI received a large military contract to design and build a family of 22 special circuits for the Minuteman missile program. At the same time Fairchild received substantial contracts from the National Aeronautics and Space Administration and from a number of commercial equipment manufacturers. To be sure, the first ICs were expensive. Though they were simple devices, containing but a couple of digital gates per package, they commanded $100 each in small quantities and perhaps half that in large volumes.

The logic known today as standard transistor-transistor logic, or TTL, evolved from work done at several sources, but can be traced back to a small company in Culver City, Calif., which was called Pacific Semiconductors Inc.

In 1960, logic ICs were employing a number of different coupling techniques between transistor stages, but each had some drawback. The yields of diode-coupled and direct-coupled logic could drop abruptly with process variations, and resistor-capacitor coupling was slow. James L. Buie, an IC designer at Pacific Semiconductors, had devised in 1961 a better coupling technique that isolated stages with coupling transistors. The key advantage of Buie's transistor-coupled transistor logic (TCTL) was that the coupling transistors offered extremely wide tolerances—thus the logic IC would have high yields. Just after Buie filed for a patent late in 1961, TRW acquired Pacific Semiconductors, and it became TRW's semiconductor division.

Other manufacturers under military contracts had developed their own logic families. In 1963 Sylvania introduced a successful transistor-transistor-logic family it called SUHL, for Sylvania universal high-level logic. Because it was one of the first commercially available families, it grew in popularity and eventually became available from other suppliers. Second sourcing—as it came to be called when one supplier's products were duplicated in all specifications by another—was an important factor in the marketing of IC logic families. Manufacturers wanted a sure supply of parts, and that meant multiple sources.

While the bipolar IC was still under development, other experimenters were drawn to the field-effect transistor. Even before Teszner had produced a junction field-effect transistor in France in 1958, many studies were under way in the U. S. on the possibilities of such a device. Researchers were lured by at least two features: the FET's use of little power and its potentially simple design.

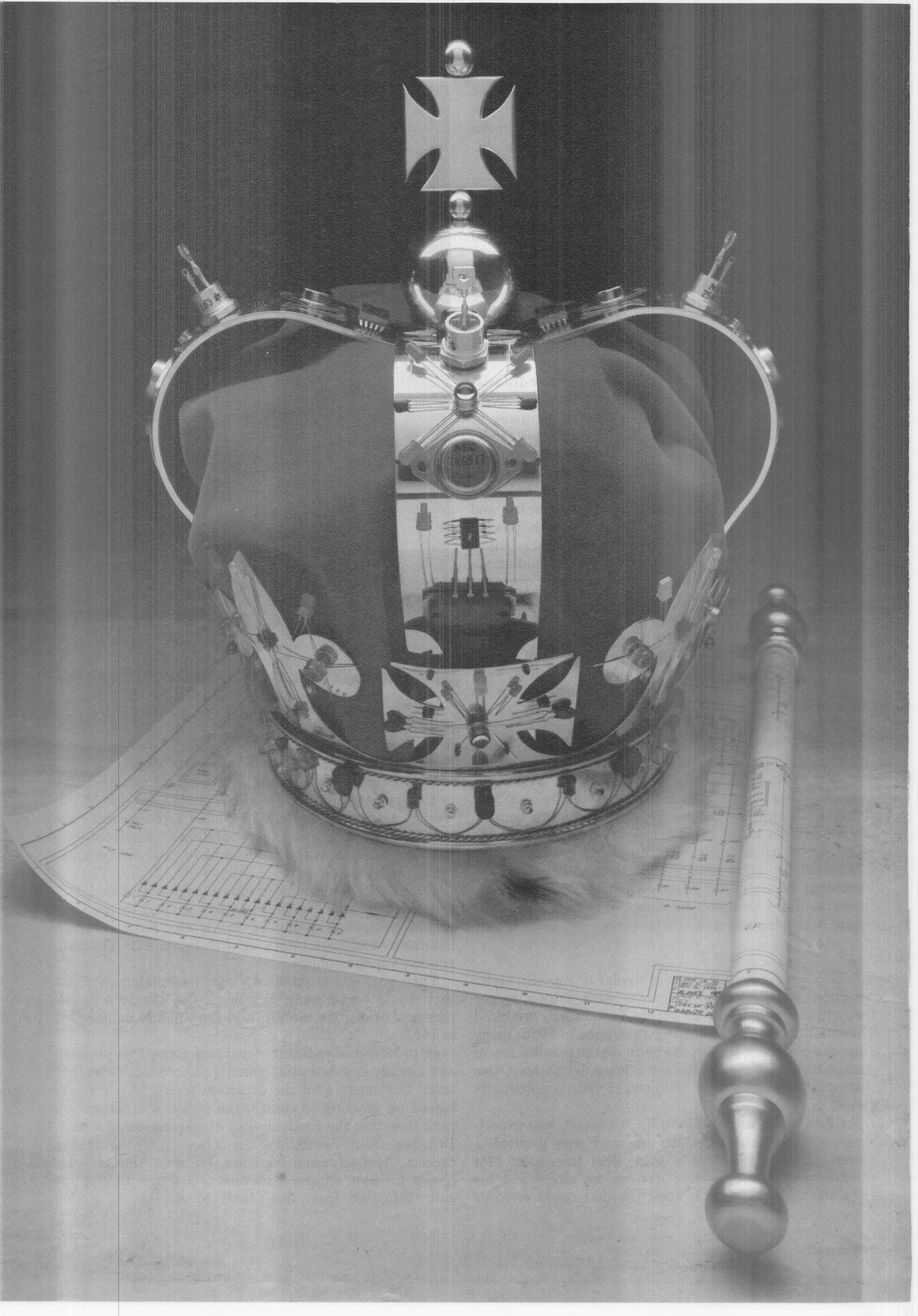
At RCA Laboratories, John T. Wallmark was experimenting with field-effect devices and was granted a patent early in 1957 for a field-effect transistor. Not thinking merely of discrete devices, he envisioned his FETs strung together into networks that could serve as logic for computers. He called his concept integrated logic nets. But although he had a patent, Wallmark never brought his concept to fruition. Two years later Paul Weimer, another researcher at RCA, did.

Weimer built working thin-film field-effect transistors in 1959, using cadmium sulfide. At the same time M. M. Atalla, a scientist at Bell Telephone Laboratories, was investigating the possibility of building an insulated-gate FET using silicon as the semiconductor and silicon dioxide as the insulator.

Then in 1959 a young graduate engineer named Steven Hofstein joined RCA. He was assigned to the integrated electronics group of RCA's electronic research laboratory and began working with Frederic P. Heiman, another young engineer.

Their goal was to produce a silicon insulated-gate FET that would be the only part needed to create a multithousand transistor circuit, and they finally achieved it in 1962.

It proved a significant departure from the junction FET already in substantial commercial production at that time. The JFETs used the depletion region of a reverse-biased pn junction to control the effective cross section (and therefore the conductivity) of a semiconductor bar. Drawing from Fairchild's development of the planar process, Hofstein and Heiman replaced the reverse-biased junction control structure of JFETs with a metal gate, insulated from the silicon by a layer of silicon



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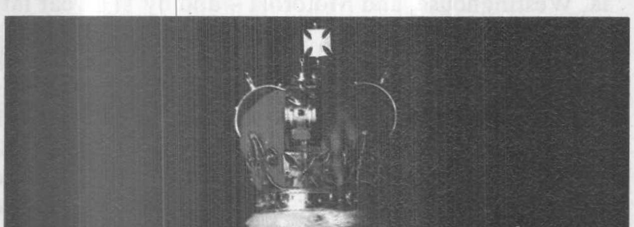

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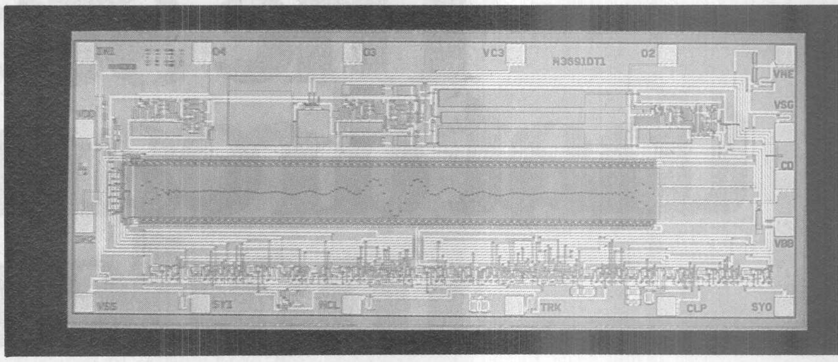


The CCD. Although developed by Bell Telephone Labs in 1970, the charge-coupled device took nearly a decade to establish itself. Intended originally as a memory device, CCD circuits proved more practical as imagers or analog filters. This chip, slightly over a quarter inch long, is a filter for detecting Touch-tone frequency pairs.

dioxide. The gate could control the current flow from one diffused region in the silicon surface (the source) to another (the drain).

Hofstein and Heiman found not only that the metal-oxide-semiconductor FET structure could restrict current flow by depleting charge but also that forward-biasing the gate with respect to the drain—something that could not be done with junction FETs—would actually enhance the charge near the semiconductor surface and thus improve the current flow. They maintained that the geometry of the new structure lent itself especially well to integrated-circuit fabrication, and they proved that late in 1962 by building a multipurpose logic block comprising 16 MOS FETs on a 2,500-square-mil chip.

By 1963 RCA had fabricated large arrays of several hundred MOS devices. The circuits were not without shortcomings, however. For one thing, they were extremely sensitive to static charge; the slightest overvoltage could break down the thin oxide and destroy an MOS device in an instant. What's more, the operating voltages of MOS devices were significantly higher than those of the bipolar logic families that emerged. MOS FETs were also very much slower than bipolar circuits.

Though the MOS FET was heralded as a significant development, it ran into commercial problems in short time. Its advantages were known from the outset: the fabrication process was far simpler than that of bipolar circuits, requiring less than half as many processing steps; it consumed far less power, and therefore a greater level of integration was possible than for bipolar devices; and it was cheaper to make. But production was plagued with oxide defects and other problems that manufacturing experience with bipolar circuits could not aid.

Few companies had the perseverance to see MOS circuits through. Fairchild Semiconductor, which was working with MOS devices in 1962, abandoned the process after difficulties and returned its focus to bipolar circuit fabrication. Even RCA, which had stayed with the MOS FET long enough to solve several of its problems, shifted its emphasis back to bipolar, the primary money-maker in the early sixties.

At about this time General Microelectronics—founded in 1963 by three former Fairchild employees, Howard S. Bobb, Robert H. Norman, and James P. Ferguson, with Arthur C. Lowell, a retired Marine Corps colonel—saw an attractive competitive spot in metal-oxide-semiconductor ICs. One of the company's major contracts was with the Victor Comptometer Corp. of Chicago, which announced plans late in 1964 to produce a low-cost desktop calculator built with 29 MOS chips instead of the 21,000 discrete components used in conventional calculators. But throughout 1965 and 1966 General Microelectronics was plagued by production gremlins.

In mid-1965 only two companies were producing MOS ICs—General Microelectronics and General Instrument—but interest in the new process was high. Many larger companies merely took a wait-and-see stance. MOS ICs took off in 1969, when shipments rose in one year in value from \$15 million to \$35 million. By the end of 1970, the total exceeded \$100 million, surpassing nearly all predictions.

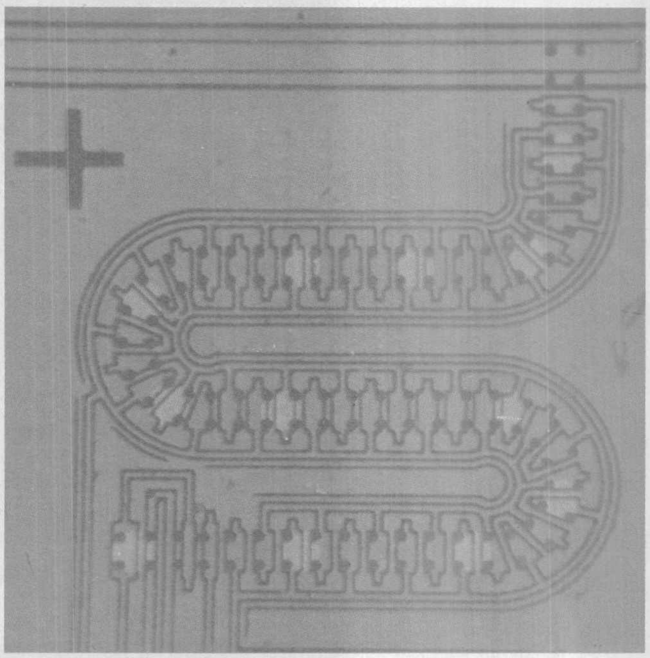
Advances in processing helped propel the industry to its heights. Electron-beam production of masks also helped revolutionize the semiconductor process. Direct writing of the mask to actual size by a microscopic electron beam sounded the death knell for huge and expensive step-and-repeat cameras, mask aligners, and ruby lithography.

Many instrument and computer manufacturers developed their own integrated-circuit expertise. Hewlett-Packard, for example, opened an IC facility in part "to guard instrument design secrets."

More than 25 companies were producing and selling ICs by the end of 1965, with Fairchild clearly the technology leader. In August of that year it introduced the dual in-line package. The DIP, designed to cut assembly time and costs, was immediately adopted by Sylvania, Westinghouse, and Motorola—and by TI a year later.

Fairchild then began forays into linear integrated circuits. One of the company's designers, Robert Widlar, had radical ideas for linear IC design. He espoused the use of transistors whenever possible to avoid using other circuit elements—a transistor replaced a large-value resistor, for example. Widlar developed the first practical integrated operational amplifier, the μA709, and then went on to design the μA702, a high-impedance op amp; the μA710, the first comparator; and the μA741, the first compensated operational amplifier that became the standard, low-cost one.

The year 1966 saw the first commercial Gunn diodes, from International Semiconductor Inc., make inroads in solid-state microwave circuits. Avalanche diodes and microwave transistors also grew in popularity. At the same time prices of discrete semiconductors, which had finally gained acceptance in new, less expensive plastic packages, were falling rapidly, and evidence of a price war was at hand. TI was offering unijunction transistors



Bubbles. Magnetic-bubble memories rely on the storage of data by the presence or absence of a tiny domain of reverse magnetization (white dots) in a thin magnetic film. Pioneered in 1969 by Bell Labs, this simple shift register had 4-mil-diameter bubbles.

packaged in plastic for 72¢ in hundreds. RCA broke the $1 barrier with triacs, the popular ac switches GE had developed in 1964. Soon all semiconductor makers had hopped on the plastic bandwagon.

Interest grew that year in sapphire as an insulating substrate material. Primarily it was Autonetics that demonstrated the density and low-power possibilities for silicon-on-sapphire (SOS) circuits; the company delivered the first SOS chip—a matrix of 6,144 diodes for a character generator in a display—to the Massachusetts Institute of Technology in 1966.

The read-only memory (ROM), which found its use first in lookup tables—such as one that produces the sine of an angle—or in character generators for displays, appeared first in early 1967. A 64-bit MOS memory organized into 16 4-bit words was offered by Fairchild. A year later Philco-Ford announced a 1,024-bit ROM. Big memories brought the term firmware—for software in ROM—into vogue.

At the end of the sixties, it seemed every aspect of semiconductor production was developing and changing. Manufacturers were planning to replace 1½- to 2-inch-wafer-processing equipment with new models to handle the 3-inch wafers becoming available. Light-emitting diodes, developed in the mid-sixties, were used in larger and larger numerical displays, while prices plummeted to a dollar a digit. The linear IC business began a scramble, as new devices cropped up weekly from the many manufacturers. National Semiconductor mixed bipolar and field-effect devices to build the LF156, the first high-input-impedance bi-FET op amp.

But on the business side, certain segments of the industry were undergoing a slump that would be partly responsible for kicking off the greatest period of executive reshuffling the industry has yet seen. The first signs came early in 1967, when TI's president, Mark Shepherd, moved J. Fred Bucy to vice president of the semiconductor division after a year of decline in new orders under division vice president Cecil P. Dotson.

In March of 1967, Fairchild was stung by a mass exodus of executives to National Semiconductor. Charles E. Sporck, general manager of Fairchild Semiconductor, left to become president of National and took with him four key men. The entrepreneurial prospects of the young, vital semiconductor industry had begun to capture the fancy of brilliant young executives. But it was the start of a bad period for Fairchild. With new business declining, John Carter resigned as chairman. Then Noyce, in line for the presidency, resigned. At the same time, research and development director Gordon Moore left for other endeavors.

With little time wasted, C. Lester Hogan resigned from Motorola to take over as president and chief officer of Fairchild Camera and Instrument. Six aides came with him. By that time, Noyce and Moore had already formed an association called Intel Corp.—and had raided Fairchild for two of its employees.

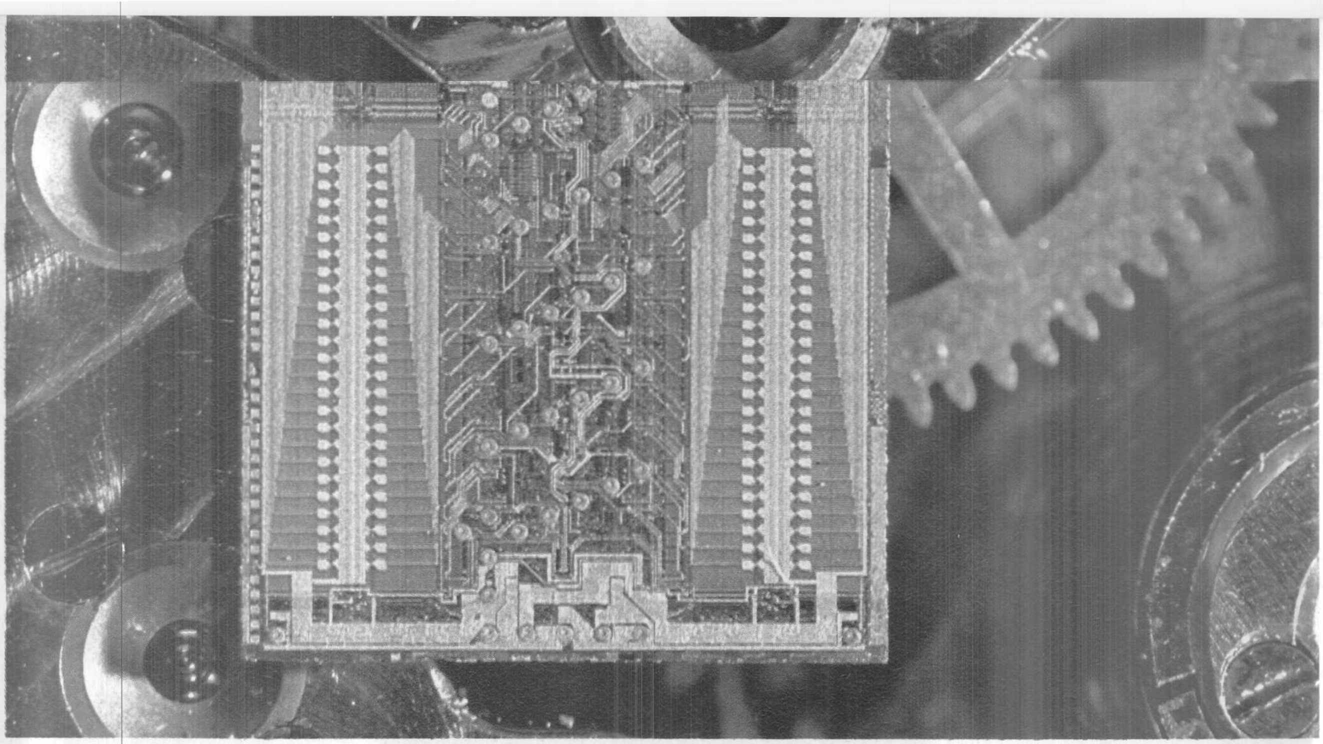
The game of musical chairs went on and on. Along with the jumps came an onslaught of semiconductor startups. Whereas three chip-making firms arose in Silicon Valley in 1966 and 1967 each, there were no fewer than 13 startups in 1968 and another 8 in 1969. Outside the valley, companies were forming as well. In 1969, ex-TI employees formed Mostek Corp. in Dallas.

The early-to-mid-1970s became an era of process competition and experimentation. Clean rooms became cleaner as circuit features got smaller. Ion implantation—the method by which impurity ions are accelerated under high potential into silicon—supplanted thermal diffusion; it had come on the scene in the mid-sixties and by the next decade would enter the production environment. It was used first for high-density memories, made easier because the ion-implantation process could introduce dopants over a greater range of concentrations and with more precise control than could the usual diffusion. Mostek Corp. was the first to use implantation in its MK4006 dynamic random-access memory (RAM).

Manufacturers of MOS devices found they could give their devices a great boost in speed by substituting n-channel for p-channel processing. The step was difficult, for the doping and control of n-MOS was far more difficult than with p-MOS. But the speed improvement was immediate: n-channel carriers (electrons) move faster than p-channel ones (holes).

Integrated injection logic (I^2L) was the engineering brainchild of bipolar manufacturers. It was devised independently at IBM in Böblingen, West Germany, and at Philips in Eindhoven, the Netherlands. The process offered the potential for bipolar circuit speed with MOS circuit density, and from its introduction in 1972, news of it spread quickly among bipolar manufacturers. It was cross-licensed and adopted for use in microprocessors, custom gate-array chips, and memories. But overshadowed by MOS, it attracted a small though steady market.

There were other approaches to processing silicon. One that seemed to defy the impossible was the floating-



On to VLSI. The era of very large-scale integration was heralded in 1979 with the announcement of 64-K dynamic random-access memories. The first, by IBM Corp., used nonstandard processing and redundant circuits to ensure good yields of the complex device.

gate avalanche cell, found in erasable programmable read-only memories, or E-PROMs. Developed by engineers at Intel in 1972, the memory element had remarkable properties: relying on an oxide-embedded silicon gate, on which a charge could be placed by avalanche breakdown of the oxide, data in the E-PROM could be erased by exposing the cells to ultraviolet light, which let the charge leak off. Moreover, the cells could be read an enormous number of times and still retain charge for many years. The first device, Intel's 2,048-bit (2-K) 1702, caught on immediately for changeable microprocessor program storage. It was improved and doubled in density almost yearly.

At about the same time, a new semiconductor storage device appeared that was to undergo a stormy journey from the laboratory to production: the charge-coupled device, developed in 1970 by W. S. Boyle and G. E. Smith of Bell Laboratories. The charge-coupling principle basic to CCDs was very simple. Carriers are stored in the inversion regions (or potential wells) under depletion-biased electrodes and moved from under one electrode to under the next by appropriate pulsing of the electrodes. Although the CCD structure promised memory densities unheard of in any type of RAM—projections of CCD chip size and cost were less than a third that of three-transistor–cell RAM designs—the realities of production fixed the fate of CCDs. The devices would mainly be used as TV camera imagers and analog filters.

A surprising process was complementary MOS. From humble beginnings as a slow, low-density metal-gate process for watch chips, C-MOS underwent scaling down, oxide isolation, and silicon-gate processing that lifted its speed and density to rival that of n-MOS, yet still dissipate only microwatt-level standby power.

In a different area of research—magnetics—a significant discovery was made in 1969 that was to have great impact on semiconductor electronics. Researchers at Bell Laboratories turned up the phenomenon of magnetic bubbles—small cylindrical magnetic domains that would remain stable under the application of an externally applied static magnetic field.

The application of bubbles as memory elements seemed almost immediately apparent: the presence of a bubble could represent a logic 1, its absence, a logic 0. The theoretical densities possible—at a time when semiconductor memories were packing but a few hundred bits on a chip—were almost incredible: millions of bits per square inch. In addition, magnetic-bubble memories were nonvolatile and therefore could retain data even if the power failed.

But though the bubbles could be made to move through an array of propagating elements under a rotating external magnetic field—which meant that bubble memories could take shape as shift registers—the design of elements to generate, detect, split, and annihilate the bubbles was far from perfected. This and the establishment of practical memory organizations and architectures held up commercial exploitation of bubble memories for nearly 10 years.

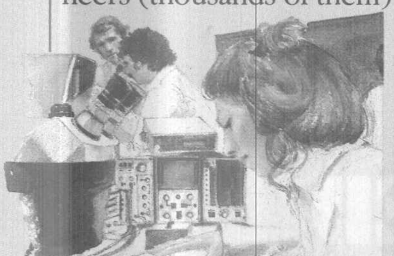
By the end of the 1970s, semiconductors had grown to a $6 billion market, and the era of very large-scale integration—hundreds of thousands of devices on chips a quarter-inch square and using lithography of micrometer line widths—was beckoning. The 64-K RAM had made its debut. It was an overwhelming prospect as the semiconductor industry faced the eighties—and a far cry from the modest "device called a transistor" announced in the New York Times of July 1, 1948.

How Nicolet fits into this box than

Fitting more oscilloscope into a cubic foot took one big first step —the use of modern digital methods. Plus a lot of little steps such as recognizing what's *"oscilloscope,"* what's not, and keeping the *"not"* outside where it belongs. Here are some of the great things the digital method has made possible.

Resolution and Accuracy

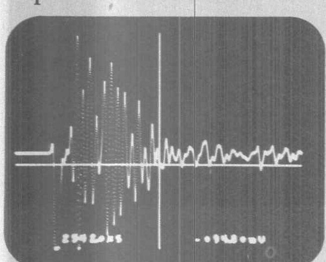
Scientists and engineers (thousands of them)



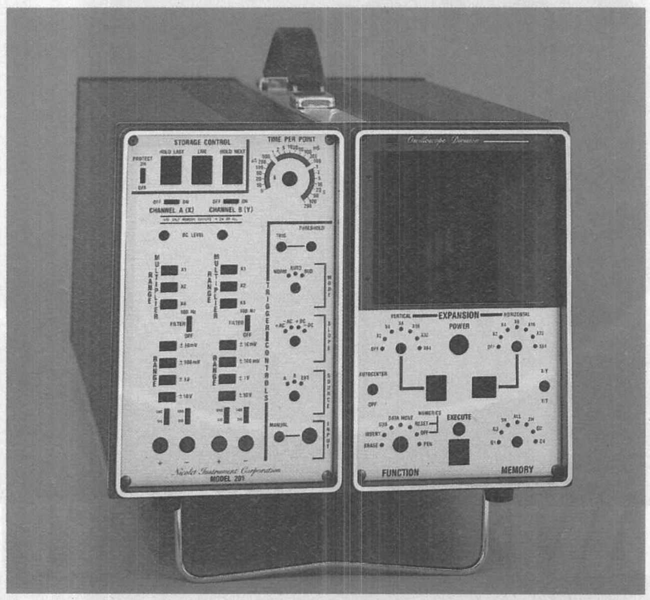
are delighted with the Explorers' 4000-line resolution, and accuracy literally an order of magnitude better than that of analog scopes and other digital scopes.

Super Storage

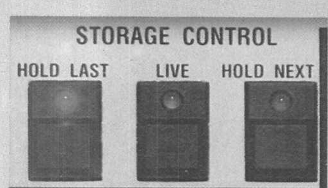
Users appreciate the Explorer's waveform



storage. At equivalent writing rates of up to 50 cm/μsec an Explorer can clearly remember, every time, without fade or bloom, literally hundreds of times as much about signals as the finest analog

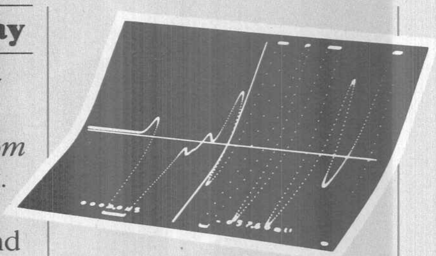


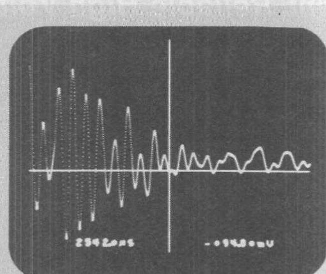
storage scopes. Best of all, Explorers store waveforms with no hassle.

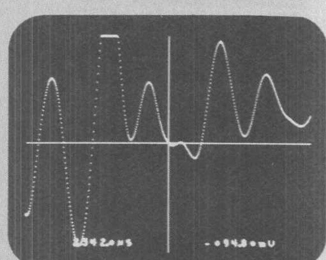


64X Zoom Display

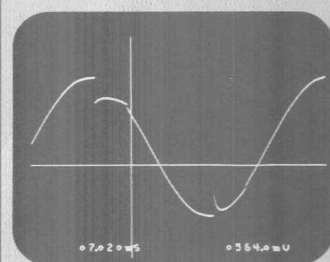
Explorer users enjoy the convenient display that allows them to *zoom in* on details of interest. They also can superimpose "old" signals and

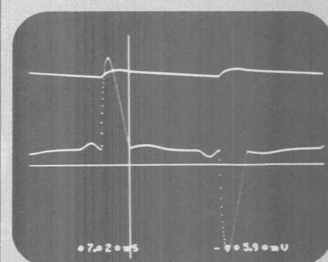


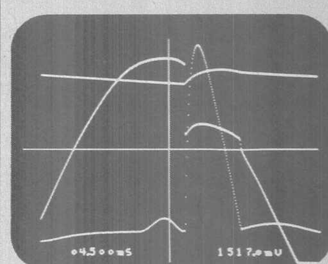




live, "fresh" signals for extremely sensitive observation of differences or changes. They can

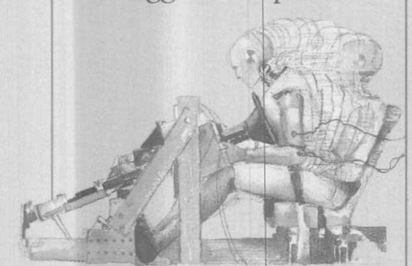






superimpose two (or four) old waveforms, or two live waveforms. And zoom in on details with up to 64X digital display scale magnification.

more oscilloscope anyone else.

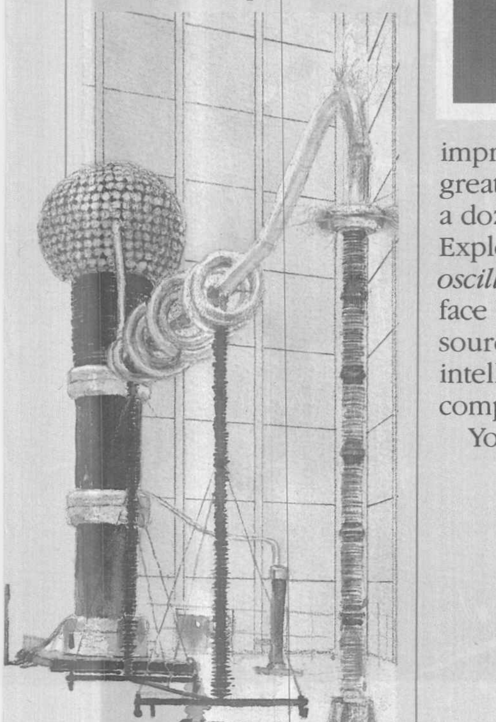


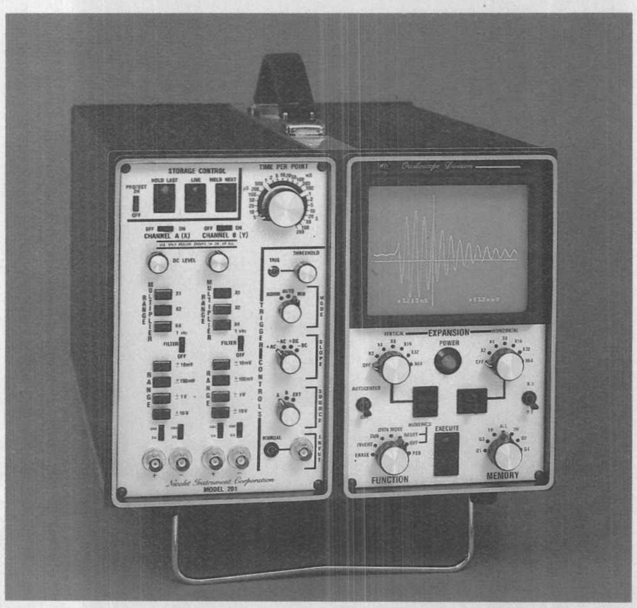
They're Pure Oscilloscopes

The digital method results in other welcome improvements. Sweep speeds that range down to days in length to allow you to precisely measure very slow phenomena. Pre-trigger sweep start allows you to see what precedes an event as well as what follows. XY operation provides even greater precision than servo-driven XY recorders, but at speeds a million times greater. Speeds as high as most analog XY oscilloscopes.

All of these are oscilloscope function improvements. The improvements include greater ease of use, for a dozen reasons. The Explorers are *"pure oscilloscope."* They interface between the signal source and the most intelligent and powerful computer in the world.

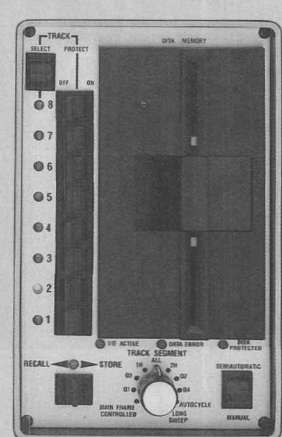
You.





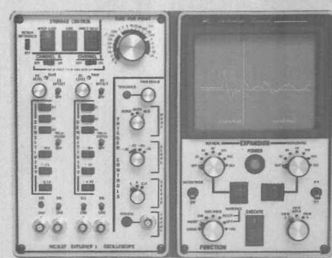
Disk Memory Option

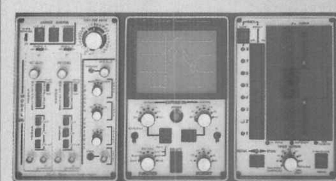
The optional, built-in disk memory can remember signals for years, storing as much data per disk as you could capture on thousands of photos. Disks are inexpensive and reusable, don't need developing, and store data at the touch of a button.



Matching Your Needs

You can choose the Explorer model that fits your measurement needs from a family of instruments, plug-ins and IEEE-488 or RS-232 options.





For More Details

To get complete information quickly, to discuss your application or to arrange a demonstration, call (608) 271-3333.

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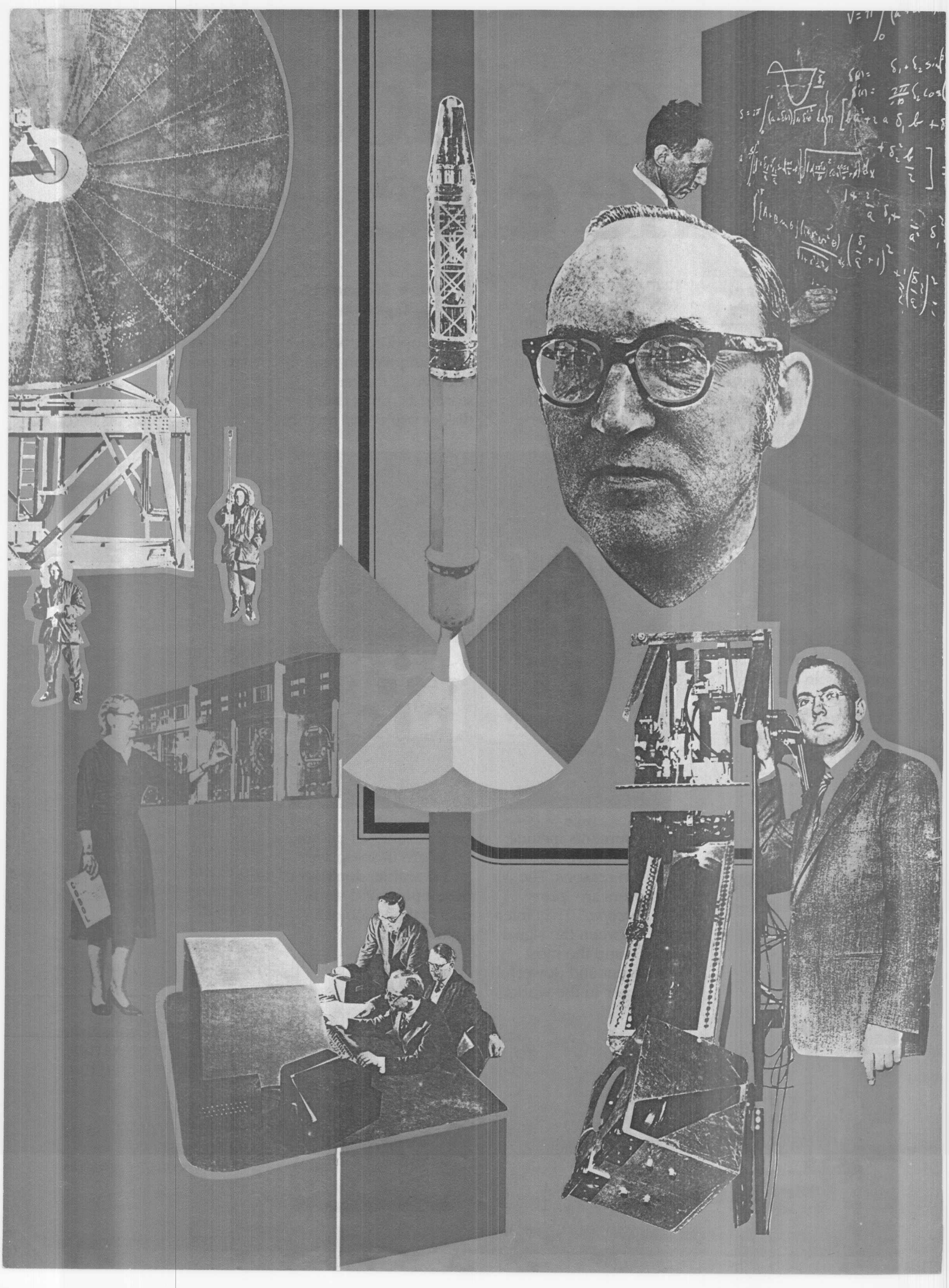

COBOL

IN THE WAKE OF THE TRANSISTOR

50 YEARS

THE SAME INVENTIVE SPIRIT THAT FOSTERED THE TRANSISTOR PROPELLED THE ELECTRONICS INDUSTRIES IN A DOZEN DIFFERENT DIRECTIONS IN THE YEARS THAT FOLLOWED. DESPITE THE COLD WAR AND KOREA, THIS DIVERSIFICATION WAS LARGELY COMMERCIAL. TELEVISION BOOMED. LONG-PLAYING RECORDS APPEARED. BIG COMPUTERS BEGAN MAKING THEIR MARK. CLAUDE SHANNON FINALLY PUT COMMUNICATIONS ON A FIRM THEORETICAL BASIS, AND THE FIRST LASER WAS BUILT. THEN THE FLIGHT OF SPUTNIK I IN 1957 PROVOKED THE U.S. INTO ESTABLISHING A SPACE PROGRAM THAT WOULD EVENTUALLY LAND A MAN ON THE MOON.

Chapter 6

a time of guns and butter. It was a time for starting planetary explorations that a scant decade before would have been unthinkable, except as science fiction. It was also a time when the sparks of inflation became noticeable, a portent of big economic trouble to come. The period was 1947 to 1960.

Though it was peace, it was turbulent peace. With each passing month, it became clear that though the Soviet Union and the West had been allies in the war against Hitler, they were widely split as partners in peace. Berlin was the first major point for a test of wills.

In June 1948 the Russians blocked all routes from East Germany to West Berlin, cutting off vital supplies to the western city. The Western powers responded with the Berlin Airlift. In May 1949 the Russians lifted the blockade.

But it was a short-lived respite in the East-West cold war. In August 1949 the Soviet Union tested its first atomic bomb, and a race to stockpile the new weapon was under way.

Korea was the second big test of wills. Hastily rebuilt American forces bore the brunt of defending South Korea from invading North Korean troops. The war ended in a truce in July 1953 after mainland China had entered the conflict on the side of North Korea.

At home in the U. S. there was fear that the sudden involvement in the Korean War would squeeze supplies of consumer goods. There was an enormous expansion of electronics in consumer and industrial markets at this time as demand, pent up by World War II, exploded. Some scare buying took place during the Korean conflict, but the familiar war shortages never developed. Manufacturing for the civilian sector continued, and the Korean War served to revive military markets for the electronics industry.

But with dollars flowing copiously for military supplies and consumer buying at home, prices crept upward. Cars that had cost $990 when the U. S. entered World War II were now $1,500 and up, and more than one conservative civilian buyer was saying: "I think I'll wait until prices come down." They never did, of course. The cost, not only of cars but also clothes, appliances, real estate, and other items, continued to rise.

The electronics industry reported record civilian sales. In March 1950 the total was put by *Electronics* at $1.1 billion. Combined with military sales, this total exceeded $10 billion by the end of 1959. Electronics manufacturing, according to Wallace B. Blood, business manager of *Electronics*, had undergone "a metamorphosis unique in industrial history."

No longer did electronics revolve around radio, as it had in 1930, when 90% of the $103.5 million in factory sales was attributed to radio. Now radio equipment represented about 20% of the electronics industry's income. The advent of television, the increasing application of electronics to industrial uses, and the expanding consumer and military markets had brought about exceptional growth.

In the July 1951 issue of Fortune, Lawrence P. Lessing wrote in "The Electronics Era": "Electronics has in progress more revolutions of profound impact upon tronics is not simply radio and television, but it is the deep-probing instrument of science, the intricate nerve center and sensory system of modern industrial power."

Immediately after World War II there had been high demand for radio sets and radio replacement parts, because of restriction on their production for civilian use during the war. Receiving tube sales rose into the hundreds of millions in the late 1940s, reaching some 400 million by 1950. This compared with 115 million tubes sold in 1940, before the U. S. entered the conflict.

But now television was also a factor. From a trickle of sets built and sold in 1947, the TV industry zoomed in 1950 to sales of $1.35 billion at the factory and accounted for roughly half of the electronics industry's gross in the U. S. The number of TV set makers climbed from 14 in 1947 to more than 80 in 1950. More than 7 million TV sets were built in 1950, as well as 8 million radios.

It was estimated that 3.1 million American homes had TV sets in 1950, and five years later the total was put at 32 million homes. The big name in telecasting in 1948 was Milton Berle. By 1952, Lucille Ball and Desi Arnaz in "I Love Lucy" had displaced Berle and Arthur Godfrey as the top-rated TV personalities.

Also hitting it big in those years was a 20-year-old truck driver from Memphis named Elvis Presley. He had a big hand in the boom of the record industry, which capitalized first on the 45-rpm record and then on 33⅓-rpm long-playing disks.

Television's first nationwide broadcasting of spot coverage of a national political convention was the Republican National Convention in July 1952. Seventy million Americans tuned in to hear the opening session called to order by the Republican national chairman, Guy Gabrielson. Later that year TV audiences watched Sen. Richard M. Nixon give his so-called Checkers speech, in which he defended himself against charges of political gift-taking when his spot on the Republican ticket as Vice Presidential nominee was threatened.

Amid all this, electronics just grew and grew. At the beginning of the 1950s, a major part of the industry was represented by about 40 tube makers that included General Electric, the Radio Corp. of America, Westinghouse Electric, Sylvania Electric, Philco, Zenith, Raytheon, and, for its own use, AT&T. Most of the big tube companies also built the tubes into finished radio and television sets and other electronic devices.

The transistor was already on the scene. The tube makers, with millions invested in their plants, saw no threat in this. "After all, they argue, some 30 years' development and refinement of the vacuum tube in hundreds of specialized forms is not likely to be upended overnight," wrote science writer Lessing in his Fortune article.

Indeed, the new vacuum tubes of which he spoke went far beyond devices destined for home radio or TV sets. Lessing pointed to metal-cavity magnetrons taken from radars and being applied to marine and aeronautical navigation systems and also to diathermy machines. He

Turning 'em out. Pent-up demand following the beginning of regular commercial television broadcasting in 1946 kept a dozen TV manufacturers like Admiral Radio Corp. busy in Chicago, turning out more than a million sets annually by 1949.

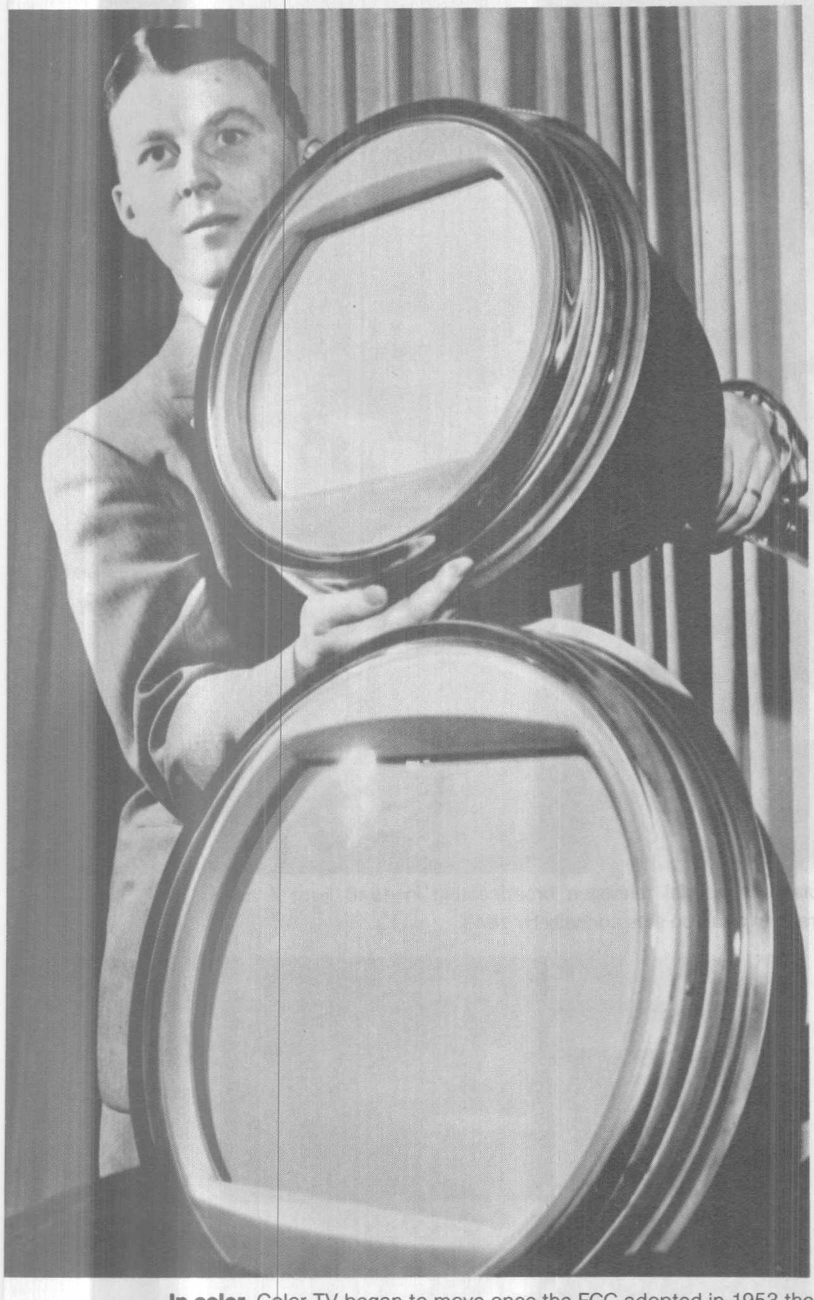
noted that klystrons were being used in television transmitters. And he singled out Varian Associates, founded in San Carlos, Calif., in 1948 by the inventors of the klystron, as an up and coming star.

Electronics companies were diversifying and some nonelectronic industries were either purchasing or creating their own electronics divisions. By 1953 the Radio-Television Manufacturers Association, which had changed its name only three years before, felt its name was no longer representative of the electronics industry. Accordingly, the association became the Radio-Electronics-Television Manufacturers Association. But the electronics industry continued to grow. Just four years later, the enlarged association became the Electronic Industries Association, its name today.

With the postwar electronics boom in so many different areas, high school graduates were attracted to college electrical engineering programs. So were ex-servicemen who had received electronics training as communications and radar technicians. They were enrolling in EE courses under the GI Bill. Just how the electronics industry would absorb the new engineers began to worry some people.

One was H. B. Richmond of the General Radio Co. in Cambridge, Mass. In an article, "An Engineer in the Electronics Industry: Prospects—Preparation—Pay," appearing in the June 1948 issue of the Proceedings of the Institute of Radio Engineers, Richmond noted that 1950 should see about a fourfold increase in the supply

Impact. Television established itself as a powerful political and social force during the fifties when it was used for nationwide coverage of the Republican National Convention in July 1952 and later to broadcast the inauguration of President Eisenhower in 1953.



In color. Color TV began to move once the FCC adopted in 1953 the National Television Standards Committee's recommendation of the dot-sequential system. RCA's shadow-mask color tube helped black-and-white compatibility. This is a 19-inch 1954 version.

of young electrical engineers with a bachelor's degree. "Taken by itself, this is not a serious employment situation," he wrote. "The problem comes from the fact that most of these people will want to engage in radar and similar war developments, and the number is greater than the current indicated need."

Many believed such statements, which were picked up and given wide circulation by the news media. It contributed in a big way to declining enrollments in engineering schools—and to a shortage of engineers that seemed to exist for much of the 1950s.

The year 1960 saw the Institute of Radio Engineers warning of another decline in the enrollment of freshmen in engineering colleges—for the third successive year—despite the launching by the Russians of their Sputnik satellite in 1957, signaling the start of a space race that would require many engineers and scientists.

The 1950s ended with membership in the IRE at a peak. The number of engineers belonging to the institute increased from about 27,500 members in 1950 to about 79,200 by the end of 1959. Somewhere around 1955 or 1956, the IRE passed the older American Institute of Electrical Engineers in total members. The AIEE finished the decade with about 55,000 on its rolls.

With war scarcities behind it and the Depression forgotten, the nation snapped up electronic consumer products eagerly from 1947 to 1960. These were years of development for television, record players, and tape recorders, and each step forward fueled the fires of buying.

After years of talk about what television would do, finally it was a pulsing reality. Sales accelerated so that Dorman D. Israel, executive vice president of the Emerson Radio and Phonograph Corp. in New York, warned: "The cost-cutting project pressure presently rampant on the TV designer's bench is closely patterned on a similar effort that struck radio in the early thirties. The lessons learned then should be applied with profit and benefit to TV today."

Color television advanced cautiously as researchers wrestled with problems of compatibility with black-and-white and the need for industry standards on this. But it was clear that black-and-white TV had benefited enormously from World War II. Not only was there impatient consumer demand, but manufacturers also simplified designs, improved production efficiency through war-learned techniques, and maintained quality.

In March 1950, *Electronics* noted that even though prices and labor costs had more than doubled since 1930, "a householder can buy a good television set with a 1950 dollar today for about what he paid for a good radio with a 1930 dollar in that period of 20 years ago."

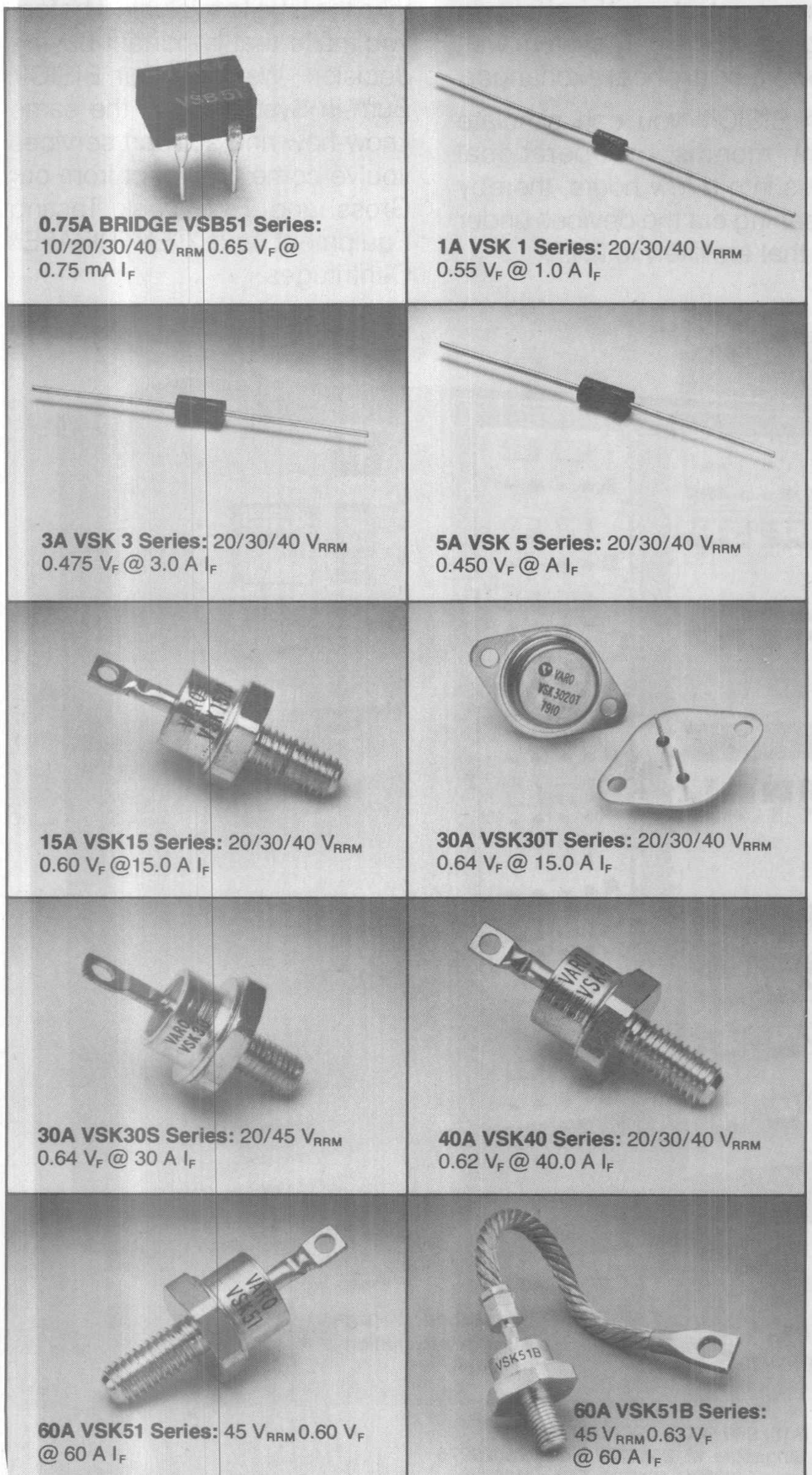
Black-and-white TV progress was swift. In May 1950, broadband television tuners were beginning to be used widely. By choosing an intermediate frequency above 30 MHz, so that the image spectrum fell outside the television band, the engineer could design a low-noise front end with a broadband rf stage and select stations by tuning the local oscillator only.

Emerson Radio and Phonograph announced that it planned to introduce a modularized TV set in March 1954, and DuMont said it was working on one (Motorola was then using modules in a portable radio). Screen sizes went up and down and back up and back down again. "Public preference for larger TV screens seems to have reached saturation," *Electronics* said in April 1956. "Now tubes under 15 inches are making a comeback."

By January 1959, however, the magazine reported that 10- and 12-inch sets had not been popular, and "current industry activity points to a leveling off now taking place, with the smallest popular picture tube sizes stopping at 14 inches."

Manufacturers pressed for battery-operated portable

Look to Varo for the widest choice of Schottky devices for power supplies.



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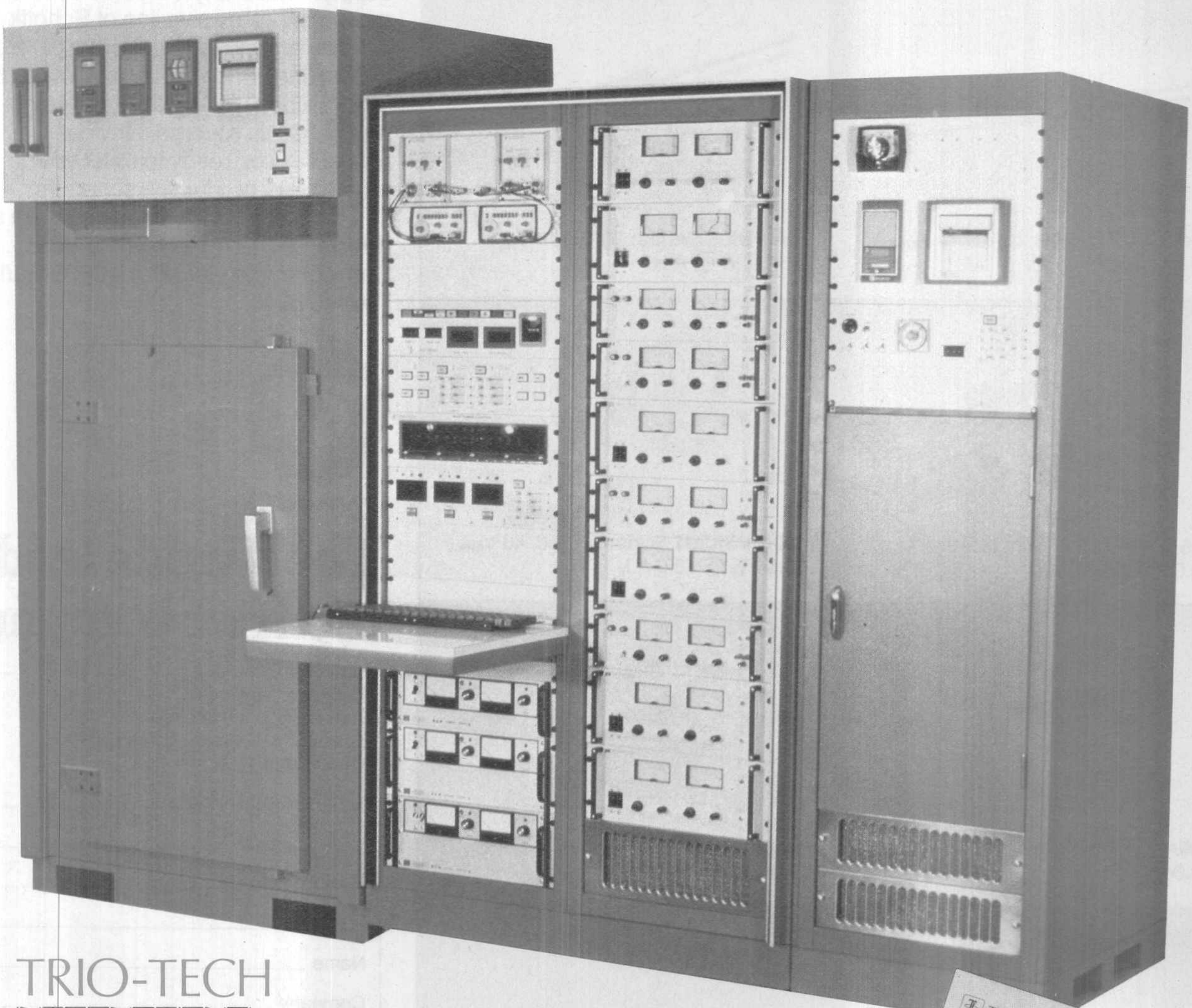

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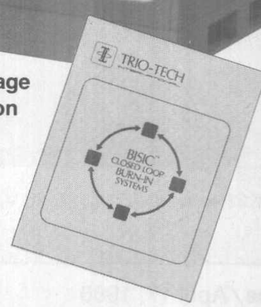


TV sets, but the problem in January 1959 seemed to be price. "The large number of specialized transistors that are called for by current designs places set costs in a range of $350 to $500," *Electronics* reported. Ac-operated portables were then selling for around $150.

Nevertheless, only six months later Philco showed a completely transistorized, battery-operated portable that listed for $250. And six months after this, Sony announced a transistorized battery-operated portable that listed for $300 in Japan.

As color television moved slowly and expensively from the laboratory to the living room, the question of frequency allocations for all television remained frustratingly unresolved. Broadcasters, receiver manufacturers and the Government tussled with the problem starting in the mid-1940s and continuing into the 1960s. There was similar agitation over color TV standards, though not as long-lasting.

In 1945 the Federal Communications Commission had allocated to television the vhf channels plus additional uhf space, 440 MHz wide, for experimental operations. But by 1948, TV was racing ahead at such breakneck speed—improvements in sets, conflicting color transmission systems, more and more receivers in homes—that the FCC "froze" all applications for television station licenses and permits pending a study of channel allocations and engineering standards for the TV set. Not until July 1952 was this freeze lifted.

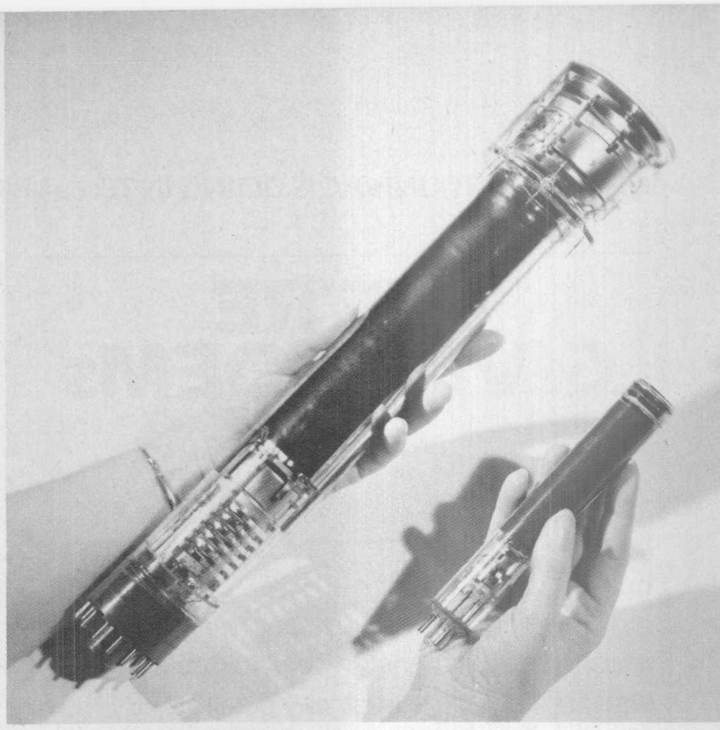
An attempt was made in 1949 to set up worldwide engineering standards for television sets. In July of that year representatives from 11 countries met in Zurich and agreed on three points: the aspect ratio should be four units horizontally to three units vertically; interlacing should be adopted and the 2-to-1 odd-line method used; and vertical scanning and the power-system frequency should be independent. There was no agreement on scanning standards.

The London Conference of the International Radio Consultative Committee was host to 22 nations in July 1950. U. S., French, Dutch, and British TV versions were inspected by the conferees. Picture brightness was compared with flicker rate, and consideration was given to modulation polarity and dot-interlace schemes for resolution improvements. But in the end, the conference concluded that as yet it was too early to mandate color TV standards.

It praised the invention of the tri-color (three-gun) picture tube, however. And it asked the French to rescind their 819-line TV scanning system, which seemed to stand apart from any system then used in Europe or the U. S.

The only point agreed to by most conferees was that a system in the 525-to-625-line range would eventually be the international standard. But there never was an international standard.

After the U. S. adopted its standard of 525 lines at 30 frames per second, most of Europe, Asia, Africa, and Australia adopted theirs: 625 lines/25 frames. Britain used 405 or 625 lines. France stayed with its 819-line system, alternatively using 625 lines. South America and



New light. A major advance for television broadcasting was the introduction by RCA in 1950 of the vidicon, shown here with its predecessor, the image orthicon. Its small size and simple, rugged construction made it ideal for portable camera applications.

Japan decided to adopt the U. S. standard.

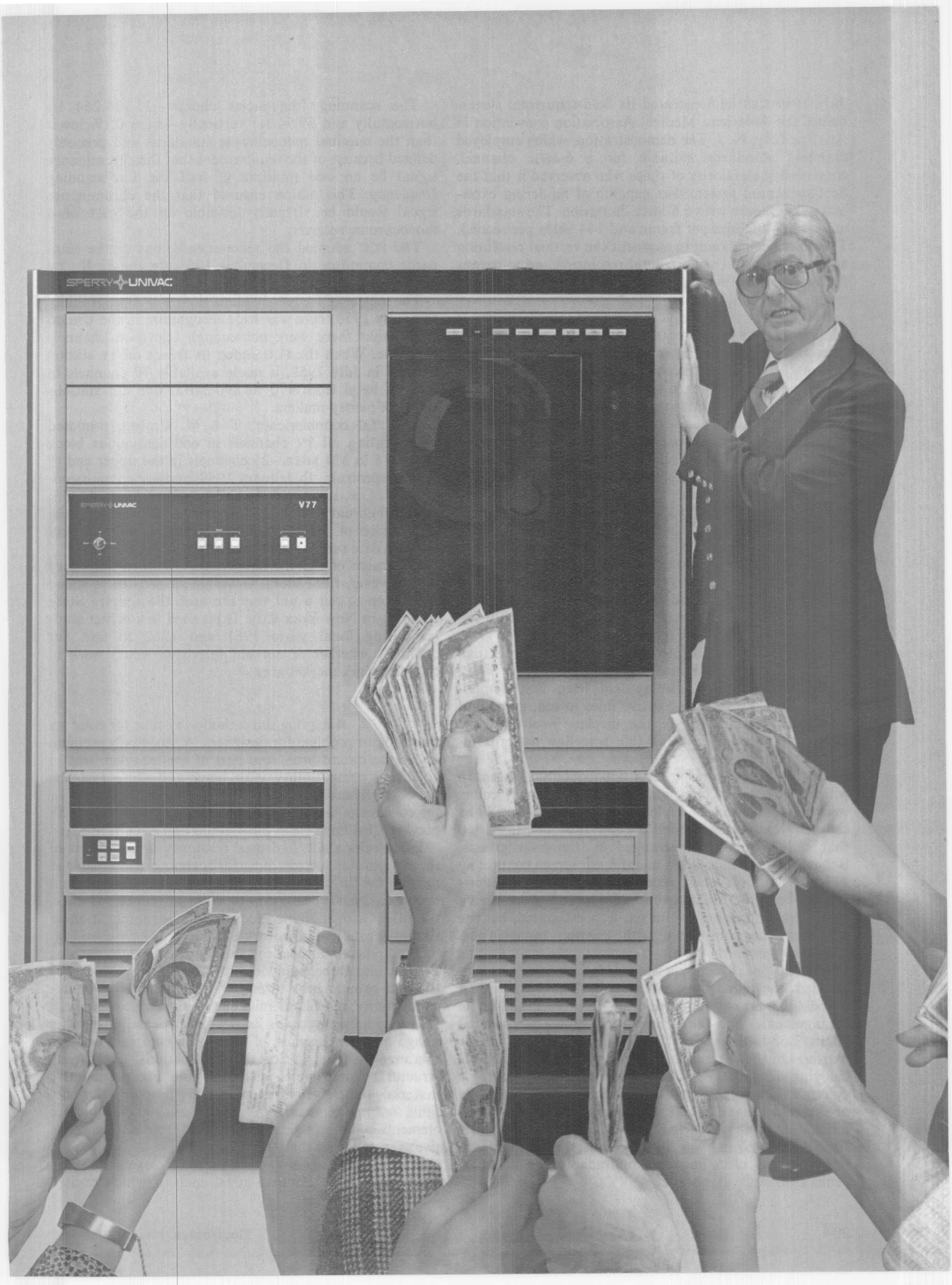
Immediately after World War II, engineers were in general agreement that a channel wider than 6 MHz was necessary for satisfactory transmission of color images and that any color system adopted would therefore be incompatible with the standards of the monochrome system. Researchers turned to the ultrahigh-frequency portion of the spectrum to develop their experimental wideband color-TV systems. The field-sequential method of transmission, put forward by CBS, was considered to hold the most promise.

The television panel of the Radio Technical Planning Board, meeting to discuss color methods at its first postwar gathering in December 1946, favored a color TV standard that would provide the same resolution and freedom from flicker as the monochrome system—525 lines per frame and 180 fields per second. But this standard implied a channel width of more than 15 MHz.

The scanning standards proposed by CBS were designed to fit the transmission into two adjacent 6-MHz channels—525 lines per frame at 144 fields per second. These scanning parameters could accommodate the color transmission in a 12-MHz channel, although the maximum highlight brightness of the images produced would be reduced to about a seventh that obtained with the 180-field system.

CBS petitioned the FCC for immediate acceptance of its wideband system in the uhf portion of the spectrum. RCA suggested that color be sent on a simultaneous basis, using the monochrome scanning standards of 525 lines and 60 fields. The monochrome receiver would be tuned to one component of this signal—that corresponding to the green primary image—by means of an external adapter. A laboratory demonstration of this simultaneous system was presented, but the system was not yet ready for field tests.

In March 1947 the FCC denied the CBS petition. But in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before the American Medical Association convention in Atlantic City, N. J. The demonstration, which employed scanning standards suitable for a 6-MHz channel, convinced the majority of those who observed it that the field-sequential system was capable of rendering excellent images, even with a 6-MHz limitation. The standards used were 405 lines per frame and 144 fields per second. They had been chosen to augment the vertical resolution at the expense of the horizontal resolution and to permit flicker-free operation at the minimum acceptable level of image brightness.

By October 1950 the FCC had made up its mind. It adopted the CBS field-sequential color standard of 405 lines and 48 color fields, interlaced, leading to a flicker rate of 48 Hz. Since this color standard and the existing black-and-white standard were incompatible, the commission indicated that TV sets should have a manual or automatic switch that would select the monochrome scanning standards in one position and the CBS color standards in the other. The Federal agency said it would have preferred a compatible color system if one had been ready for commercial use.

RCA carried its opposition to the FCC ruling to the Supreme Court, which in May 1951 upheld the FCC's order. On June 25, 1951, regular color telecasts to the public began in New York City with the CBS system.

It was to be more than two years—December 1953—before the FCC reversed its decision and approved a compatible color-TV system. In the interim, confusion and contention swept the television industry.

At least two compatible systems were in contention: the line-sequential and the dot-sequential.

The line-sequential display had been first demonstrated in 1949. In it, successive lines in red, green and blue were scanned. Since the display involved triple interlace, however, objectionable traveling patterns intruded on the picture.

RCA had been working on a dot-sequential system in which three sets of phosphor dots in the primary colors were interspersed in sequence along each line. The company had demonstrated a color tube in May 1950 that had 351,000 dots arranged in triangular groups. Behind the tube face was a metal mesh screen containing 117,000 holes. A color receiver using a new shadow-mask tube would probably cost 20% to 25% more than a comparable black-and-white set, RCA estimated, but the set would be compatible with existing monochrome broadcast standards.

The National Television Standards Committee recommended the dot-sequential system. The standard it proposed was an adaptation of the black-and-white arrangement, with a chrominance subcarrier located about 3.58 MHz above the frequency of the picture carrier. On the chrominance carrier would be two color-carrying signals that would be added to the monochrome system's luminance signal to provide hue and saturation of the color image. The chrominance carrier was to be modulated in phase to change hues. Saturation information, sent by a-m, was to represent the ratio of the instantaneous chrominance amplitude to the instantaneous luminance amplitude.

horizontally and 59.94 Hz vertically—were 0.1% lower than the nominal monochrome standards and precisely defined because of the requirement that the chrominance signal be an odd multiple of half the line-scanning frequency. This action ensured that the chrominance signal would be virtually invisible on the CRT of a monochrome receiver.

The FCC adopted the recommendations of the standards committee in December 1953. In the U. S., TV color compatibility was no longer a problem.

The matter of frequency allocations was more troublesome. By 1950 there was wide recognition in the United States that there were not enough television channels available. When the FCC ended its freeze on TV station permits in July 1952, it made available 70 channels in the uhf band from 470 to 890 MHz. But uhf stations were not money-makers.

One FCC commissioner, T. A. M. Craven, proposed consolidating all TV channels in one continuous block from 174 to 324 MHz—25 channels in the upper end of the vhf spectrum. In January 1959, another commissioner, R. E. Lee, suggested that all television be made uhf. And in February the FCC chairman, J. C. Doerfer, said: "Expansion of the vhf band is the logical solution and would create the least disruption."

Expansion of the vhf band it was. Rather than bury uhf, however, the Federal Government decided to spend $2 million to put a uhf test site atop the Empire State Building in New York City. It planned to conduct studies during fiscal years 1961 and 1962 to find out definitely whether or not uhf television would work in the New York market area.

Adapting the cathode-ray tube for color TV was a major problem for designers. A secondary problem lay in the circuit area, and part of this problem was in achieving compatibility with black-and-white systems. RCA is generally credited with introducing major improvements in CRTs and the Hazeltine Corp. with playing a leading role in the systems and circuits arena.

Early color CRTs had used a clumsy arrangement of three separate electron guns for scanning and a bank of mirrors for the color-mixing process. Researchers developed two basic tubes: one with three self-contained guns, the other with a single electron gun scanning at three times the rate to do the work of three guns.

The vidicon, announced by Paul Weimer, Stanley Forgue, and Robert Goodrich of RCA in May 1950, was the first camera tube to employ the principle of photoconductivity, not photoemission, as its predecessors had. Its major advantage was its size; it was smaller than an image orthicon because of its simple construction, and this made it ideal in portable applications. Because no structural limits were placed on the photoconductive material, the electronic scanning spot imposed the only limit on image detail. As many as 200,000 picture elements could be accurately scanned from a photosensitive area no larger than 0.2 square inch.

Harold Law's shadow-mask tube, developed at RCA in 1951, used three electron guns, each of which excited

were so placed as to beam electrons through an apertured plate (mask) onto the phosphor screen placed parallel to it. The screen contained 900,000 holes, arranged in groups of three to correspond to the groups of red, blue, and green dots. Three signal-processing circuits were used to feed the red, green, and blue scanning signals between the grid and cathode of each gun. Color mixing relied on the human eye's ability to retain three-tone images produced by each dot group.

A version of this tube was in RCA's dot-sequential system, which was shown to the FCC in hearings on color compatibility in June 1950. Despite its drawbacks—screen brightness limited by the brightness of the image; the need for precision mask alignment; and the need for congruent scanning patterns—the tube was widely used until about 1970.

E. O. Lawrence's single-gun Paramount tube, developed at the University of California in 1951, used 1,200 horizontal strips of phosphor arranged in a repeating red-green-blue and blue-green-red pattern to overcome the mask and scanning disadvantages of the shadow-mask tube. Deflection plates running parallel to the phosphor lines were used to deflect the scanning beam selectively, so that it could be focused on any of the phosphors at instants when the video signal amplitudes were appropriate to control its luminance.

The Lawrence invention never achieved practical importance because of its need to switch from phosphor to phosphor periodically, which inherently lowered screen brightness.

There were other improvements that from a system viewpoint were just as important as tube advances. The Hazeltine Corp. introduced in 1950 a new method for processing so-called dot-sequential images. The constant luminance technique removed the dotlike appearance of observed images, reduced the tendency of finely colored areas to shimmer, and made the image less susceptible to rf interference, all while using a 4-MHz video channel.

The images provided by the constant-brightness method were reported to be of such high quality that they were indistinguishable from those attainable with a 12-MHz TV channel.

Sales of color TV sets were somewhat disappointing after the FCC swing to compatibility standards in 1953. There was not the rapid growth that had marked the expansion of black-and-white TV in 1947–48.

RCA began commercial production in December 1954 of receivers using its 21-inch color tube, with a retail suggested price of $895. Hoffman Electronics planned limited production using the RCA color tube and a price range of $895 to $995. Other companies that announced limited production included Admiral, DuMont, Emerson, Motorola, Olympic, Magnavox, and Sentinel. Westinghouse introduced a set employing a 22-inch rectangular all-glass color tube for a table model that was not much larger than a 21-inch black-and-white set.

Industry executives estimated that retailers would sell between 50,000 and 750,000 color TV sets during 1955; the average of all guesses was 300,000. In fact, the industry sold about 35,000 sets.

Short take. Another nail in the coffin of the 78-rpm phonograph system was the 45-rpm record and changer introduced by RCA in 1949. Earlier, the 33-1/3 rpm long-playing system devised by CBS Laboratories started the revolution in the recording industry.

There were not enough color tubes. RCA was producing only 2,000 a month during much of 1955. There were not enough color programs being telecast. And the sets were deemed too expensive.

In July 1956, RCA and Admiral both introduced color sets listing for less than $500 retail, and the number of TV stations that could obtain network color programs over Bell System facilities reached 203 in 141 cities. By contrast, there had only been 130 stations in 101 cities at the end of 1954.

Growth continued cautiously. TV retailers sold fewer than 100,000 color sets in 1956. The industry did not sell a million color sets in a year until 1964.

The phonograph industry, meanwhile, was in the throes of a revolution. Peter C. Goldmark, Rene Snepvangers, and William S. Bachman of Columbia Broadcasting System Laboratories announced a new long-playing record in June 1948, and the industry never was the same again. The 33⅓-rpm LP disk could play as long as 50 minutes, compared with 8 minutes for a 78-rpm record. The grooves of the newcomer were 2.6 mil wide, against 6 mil for the 78-rpm record. The bottom radius was 0.2 mil, against 1.5, and the LP disk had an average of 260 grooves per inch of radius, compared with 100 for the 78-rpm record.

It was not the first time that 33⅓-rpm disks had been

On guard. Computer-controlled operator consoles built by IBM were part of the high-performance ground radar system known as Sage, an ambitious aircraft defense system developed for the Defense Departmen, deployed in the U. S. and Canada, and linked by computers.

produced for the home market. They had been tried as early as 1931 as part of an attempt to offer movies with sound; the disks played as long as a single reel of film. But these attempts failed because the engineers could not cut the groove pitch fine enough to secure a substantial increase in recording time; the noise and distortion were high.

Keys to the new LP were Vinylite plastic for the pressings, a new efficient, lightweight tone arm and cartridge, and mechanical refinements in the turntable driving mechanism.

In March 1949, RCA introduced the 45-rpm record and changer. The groove width was similar to that of the LP, but the smaller record, turning more rapidly, could hold only about 5 minutes of sound. The system's advantage was the fast, simple changing mechanism built into the phonograph's center post; the player held eight records, for about 40 minutes of playing time.

Despite the clear advantages of the LP for classical music and the 45 for popular, the 78 was still outselling both as late as 1954. In that year the industry shipped 121 million 78s worth around $24 million, 76 million 45s worth some $21 million, and 24 million LPs valued at about $22 million.

There had been two approaches to stereophonic disk recording: the vertical/lateral technique and the 45/45. In the former, one channel was recorded vertically and the other laterally in a single groove. In the 45/45 technique one channel was identified with a 45° motion on the inside groove wall and the other channel with a −45° motion on the outside groove wall. The quality of most of these early stereo disks was poor, however; they suffered from mechanical difficulties, including cross-coupling between the channels.

But by 1957 vertical/lateral equipment had reached the commercial stage. And a commercial 45/45 stereo system was also announced in 1957. The Standards Committee of the Recording Industries Association of America adopted the 45/45 as technically superior to the vertical/lateral system. It was one of the rare times that the consumer electronics industry had decided on a standard before producing competing equipment.

There were improvements also in turntables, amplifiers, and speakers. Transistors first appeared in high-fidelity gear in a humless preamplifier-equalizer in early 1956. The Fisher Radio Corp. mounted three transistors on a printed-circuit board to boost a low-level input sufficiently to drive a conventional amplifier system. The transistors permitted the engineers to match the input to low-impedance magnetic cartridges without resorting to transformers.

There were also dramatic advances in tape-recording equipment. *Electronics* reported in August 1948: "Magnetic tape carrying three simultaneous channels gives a striking illusion of presence when played back through properly oriented speakers." Much of the stimulus for the stereo disk apparently came from the success of recorded stereo tape. The three channels were flat within 5 decibels from 50 to 10,000 cycles. "At the normal running speed of 1 foot a second," the magazine noted, "a full reel of quarter-inch tape plays for 20 minutes." Of course this oddball tape machine did not set the standard for the medium, which settled for only two channels at 7½ or 15 inches per second.

In June 1955, RCA announced an experimental color video tape recorder, and Ampex planned to deliver three prototype video tape recorders to CBS by August 1956 and to begin commercial production of the machines in February 1957. The prototypes sold for $75,000 each. RCA announced a new color video tape

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	MN1405	40 Pin DIP/Plastic	2048 x 8 bits	128 x 4 bits
	MN1498	40 Pin DIP/Plastic	External	64 x 4 bits
P-MOS	MN1430	40 Pin DIP/Plastic	1024 x 8 bits	64 x 4 bits
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	MN1435	40 Pin DIP/Plastic	32 x 4 bits	16 x 4 bits
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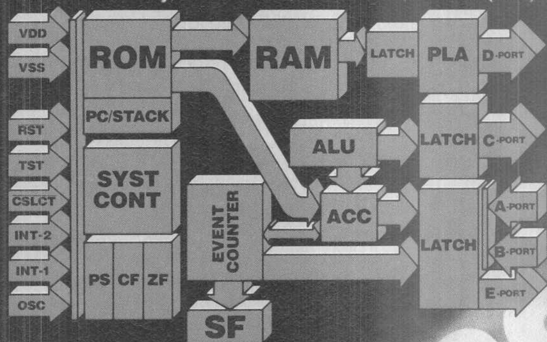

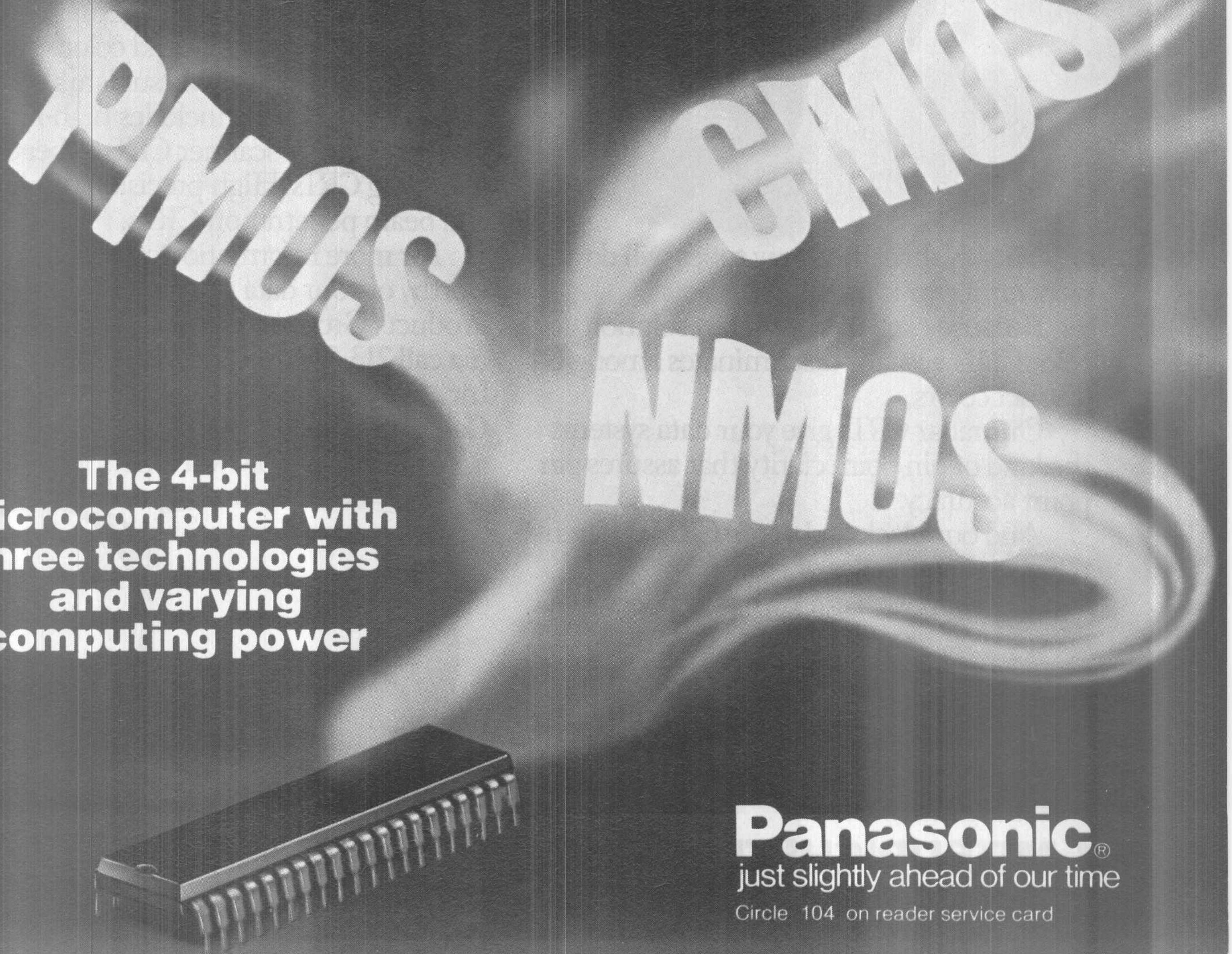

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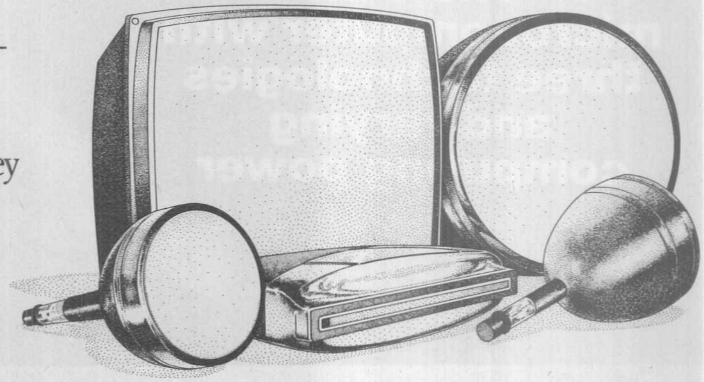

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The consumer audio tape recorder business grew from about 255,000 units in 1954 to 700,000 units in 1959.

Radar, which had spurred dramatic improvement of the cathode-ray tube during World War II and thereby had laid a sound foundation for television growth in the postwar years, underwent refinement from 1947 to 1960. There were improvements in components, circuitry, and the processing of received data. There were new methods for detecting moving targets.

In the military sector, the ever higher megawatt powers available in transmitters and the ever greater sensitivities of receivers led to the development of long-range radars capable of detecting ballistic missiles. At the same time the development of the pulse-doppler technique allowed for supersensitive radars for ground surveillance and personnel detection.

The civilian sector saw commercial and marine vessels increasingly employing radar aids to navigation, and highway police started to use a form of continuous-wave radar for the detection of speeding vehicles.

Military radar did not begin major development past the World War II stage until the mid-1950s. This is well illustrated by the fact that the SCR-584 long-range search radar was still used in various forms by the military forces of the North Atlantic Treaty Organization until 1955. But by then long-range bombers, missiles, and nuclear weapons were on the scene, and they made it possible for one country to wipe out another with just one surprise attack. The U. S. deemed it necessary to have a long-range radar system to give warning of such an attempt in enough time to mount both defensive and offensive action.

Older radars lacked both the range and sensitivity, and the quickness of response to do the job. What is more, they could not distinguish fast enough between a potential enemy and the hordes of civilian aircraft that now filled the skies. Fortunately the automatic operation that was required for the new job became available in the mid-1950s with the advent of high-speed digital computers. These made it possible to mechanize the gathering and analysis of radar data.

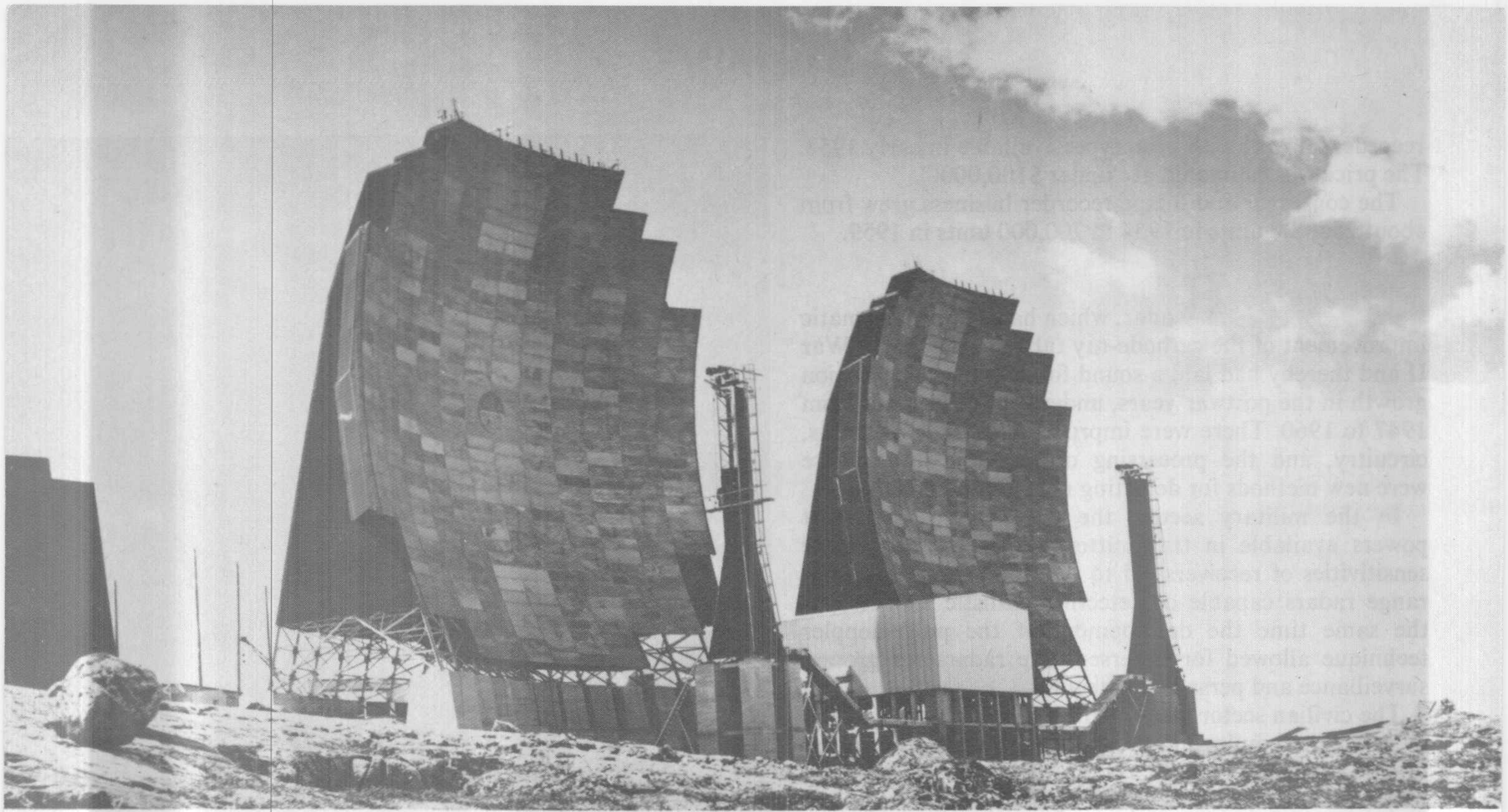
The most ambitious undertaking of this sort was the development by the Department of Defense of the semi-automatic ground environment (Sage) system. It was designed to control weapons defending the U. S. against air strikes.

High-performance ground radar sets in the Sage system were installed in the U. S. and southern Canada and pointed toward the North Pole. These gave almost complete coverage of the skies except at low altitude. This was the traditional weak point of the system, due to ground radar returns and the curvature of the earth.

These radars were linked to central computers, which, among other chores, identified civilian flights from flight plans stored in their memories and directed interceptor aircraft to unidentified planes. But all this was not enough as aircraft got faster and faster and the time available to react to an attack became shorter and shorter. More and longer-range installations were put up in the 1950s in mid-Canada. This Distant Early Warning (DEW) line, which cost $1 billion, was able to detect and locate the faster aircraft but not missiles. So the DEW line was superseded by the Ballistic Missile Early Warning System (BMEWS).

Outpost. As aircraft speeds got higher and higher, available reaction time to an attack required longer-range equipment. This Distant Early Warning (DEW-line) station was one of a chain of such installations set 200 miles apart in mid-Canada.

The first BMEWS station, built in Greenland in 1959, had four antenna arrays, each standing 165 feet high. The transmitters put out more than 2 million watts of peak power in two fanlike beams, one above the other. These were pointed at the North Pole and were capable of detecting a missile 3,000 miles away when it reached a



Missile seeker. This pair of antennas was part of the Ballistic Missile Early Warning System (BMEWS) built by Western Electric in Labrador. BMEWS could detect missiles 3,000 miles away at a height of 600 miles, giving about 20 minutes of warning.

height of 600 miles. Two sets of data—received as the missile passed through first the lower and then the upper fan beams—enabled computers to calculate the missile's course and to give about 20 minutes of warning.

While the early-warning systems were perhaps the highlight of radar development of the time, other military applications were not ignored. Small combat surveillance radars, for one, resulted from the need to detect such moving targets as a creeping soldier or a moving Jeep or tank. Such radars were built in the mid-to-late-1950s, and they incorporated a combination of both continuous-wave and pulse-wave techniques. They were dubbed PD (for pulsed doppler) radars, and several types were built. One was a small, portable set called the Silent Sentry.

The Silent Sentry was able to detect moving tanks or troops 3 miles away by converting the radar echoes it received into audible tones in an operator's earphones. As reported in *Electronics* in the issue of Aug. 14, 1959, the Silent Sentry could tell the difference between a man and a woman on the basis of how they walked. The difference in the sound also made it possible to discriminate a walking person from a running person up to a half a mile away. The location error was less than 25 yards. One version—the AN/PPS-4, produced by the Sperry Gyroscope Co. in Great Neck, N. Y.—had a usable range of up to 5,000 meters.

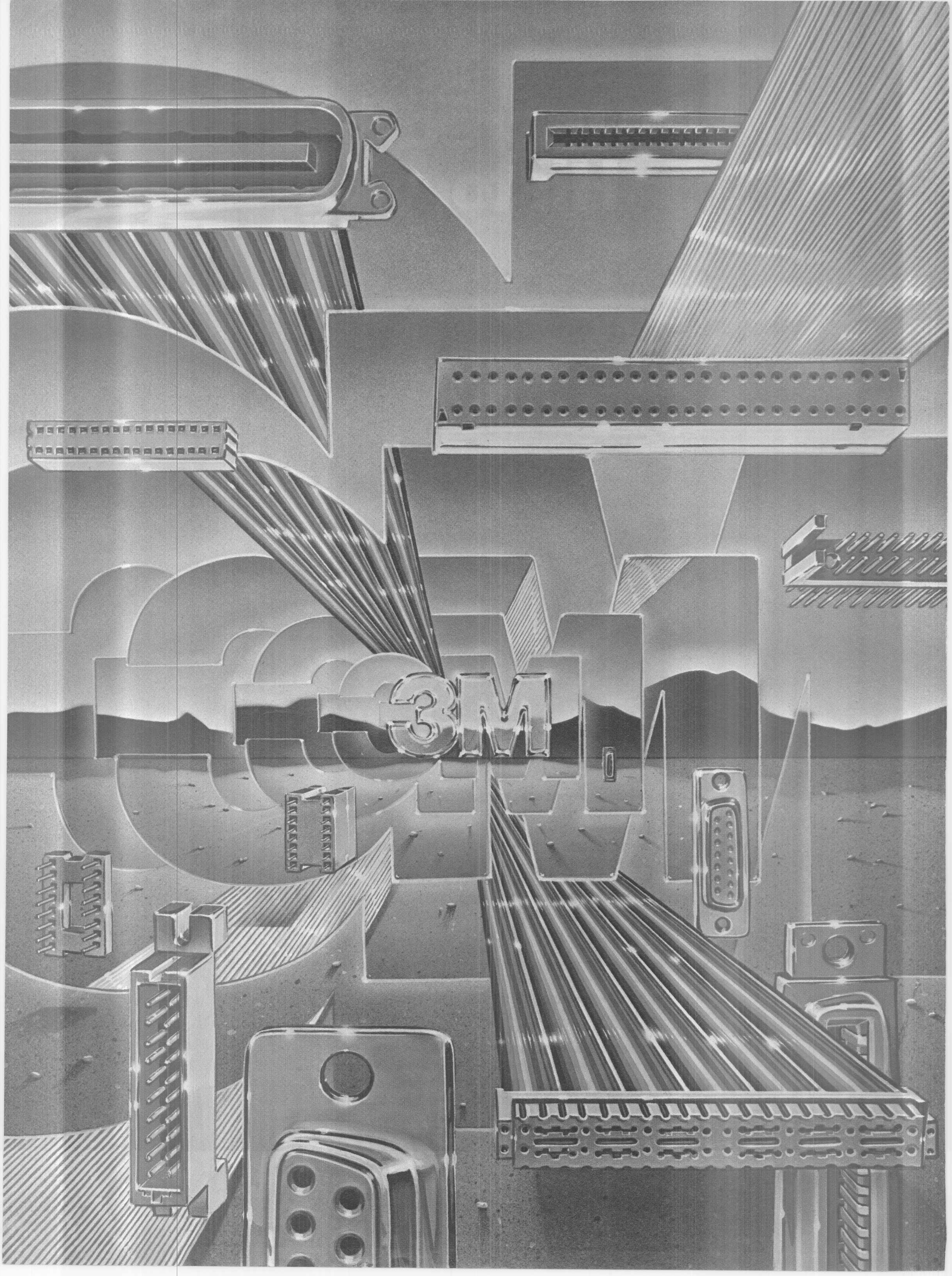
Another remarkable radar development of the late 1950s flowed from the military need for surveillance of areas without flying directly over them. This led to the development, by the University of Michigan and the U. S. Army Signal Corps, of a side-looking, terrain-mapping radar that provided a permanent record. With this device, the return echoes from a radar transmitter mounted in an airplane were recorded on film during the surveillance flight. The film was then developed and processed by a computer to enhance the received image. The final result was a detailed picture of the scanned area, as if the plane had flown directly over it.

Civilian airborne radars were not neglected. The U. S. Civil Aeronautics Administration (which later became the Federal Aviation Administration) promoted the installation of ground-controlled approach (GCA) radars. Once these were in place at major airports, traffic controllers could observe airliners approaching in bad weather or at night and "talk" them down to a safe landing by means of radio.

The impact of the transistor on radar was limited in the 1950s. This was because transistors were not yet readily available for this application at reasonable cost. It is not surprising, then, that early uses of the transistor in radar were in the low-frequency, or signal-processing, circuits and not in the high-frequency, or transmission, portions of the system.

The end of World War II signaled the beginning of the growth period for electronic digital computers. Unencumbered by wartime secrecy, the technology flourished, and the computer became a commercial product that soon changed the industrial world. Scientists and engineers who had worked on wartime government computing projects returned to civilian life and contributed to the growth of the industry on both sides of the Atlantic.

Although Britain and the U. S. were neck and neck in early development of the computer, the U. S. began to take a clear commercial lead during the 1950s. Analog computers advanced with the invention of the operational amplifier in the early 1950s, but it was a short-



lived advance. Almost immediately the analog approach was overtaken by the rapid pace of digital progress.

While the concept of storing the computer's instructions and data electronically had originated in the U. S., the British were the first to implement the technique. Tom Kilburn and Frederic C. Williams ran the first program on Manchester University's Mark I computer on June 21, 1948. Using a single Williams storage tube that held 32 32-bit words for main storage, and similar tubes for the accumulator and control register, the serial Mark I performed one instruction each 1.2 milliseconds. Maurice V. Wilkes's group at Cambridge University in England ran its first program on its Edsac computer on May 6, 1949.

Meanwhile John W. Mauchly and J. Presper Eckert, the Eniac pioneers who were now established in their own company, had begun early in 1948 to design the binary automatic computer, or Binac, for the Northrop Aircraft Co. With mercury delay lines as the storage medium, the Binac was finished in 1950. The stored-program concept had been proposed earlier for the Edvac computer, which was finally finished in 1950 at the Moore School of Engineering at the University of Pennsylvania.

An electronic automatic computer called Seac was built at the National Bureau of Standards and put into operation in May 1950. In its September 1950 issue, *Electronics* called the serial synchronous machine, which sent signals at a 1-MHz rate, the fastest computer then in operation.

At the Massachusetts Institute of Technology, another significant milestone was reached when Whirlwind I was completed in March 1951 after six years of development. The project had begun at MIT's Servomechanisms Laboratory in 1944 as an effort to develop an airplane stability and control analyzer for the Navy. The project engineers—especially the laboratory's assistant director, Jay W. Forrester—realized that digital computing techniques were needed for the real-time analysis of data. The result was a 5,000-tube, 11,000-diode machine that operated on 15 binary digits.

While most of the other machines in 1951 operated serially—that is, transmitted the numerous bits representing numbers through the machines one at a time—Whirlwind handled the data in parallel fashion, the way Eniac had. Forrester's group had recognized that transmitting the bits together across a set of parallel wires would speed the machine's operation and ease the synchronization requirements.

But lack of a fast memory was a stumbling block for computer designers in the early 1950s. Research concentrated on the storage properties of toroids of magnetic material strung on a matrix mesh of wire—the so-called coincident-current magnetic-core memory.

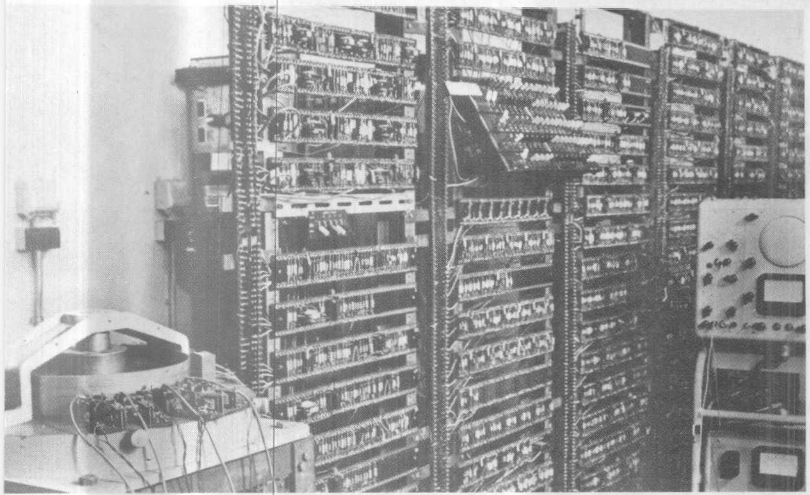
In January 1950, An Wang (now chairman of Wang Laboratories) and W. D. Woo described work on the magnetic material in the Journal of Applied Physics. In the same journal in January 1951, Forrester described the application of the magnetic-core technique to digital information storage, and in 1953 the Whirlwind computer got core memory.

Magnetic-core technology, perfected during the 1950s, offered large, fast, and economical memory to computer designers, and it revolutionized their work. The computer was now ready for mature growth. Eniac, the machine credited with starting it all in 1946, was turned off for the last time on Oct. 2, 1955, at the Aberdeen Proving Grounds in Maryland.

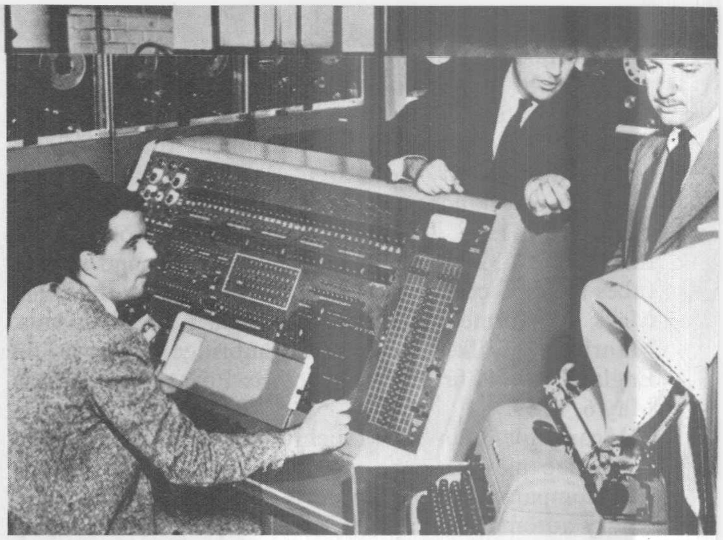
The commercial development of the computer soon

Silent Sentry. That was the nickname of the AN/PPS-4 portable combat surveillance radar produced by Sperry Gyroscope Co. in the mid-1950s. With a usable range of up to 5,000 meters, it converted radar returns into audible signals using a pulsed doppler principle.

First run. Though the stored program idea originated in the U. S., the British tried it first in the Mark I computer at Manchester University. Shown here in 1952 are (from left) the university's T. Kilburn and manufacturer Ferranti's B. W. Pollard and K. Lonsdale.



Transistors arrive. Another first for the British was this experimental computer assembled at Manchester University, with germanium point-contact transistors. Using a magnetic drum as main store, it was slow but probably the first stored-program transistor computer.



In the news. Eisenhower's victory in the 1952 presidential election was projected by Remington Rand's Univac I computer for CBS-TV. A young Walter Cronkite is at far right. The Univac family was responsible for many technological innovations in computers.

turned into one of the most spirited competitions in the electronics industry. A late starter, the International Business Machines Corp. prevailed. By 1959 it had clearly become the dominant computer manufacturer in the world. But the biggest supplier at the beginning of the 1950s was the Remington Rand Corp., a leading typewriter manufacturer and second only to IBM in the production of punched-card equipment. In 1950 Remington Rand acquired the first commercial computer manufacturer, the Eckert Mauchly Computer Corp.

The distinction of delivering the first commercial computer belongs to Ferranti Ltd. in England. Working with Manchester University, Ferranti delivered its first commercial Mark I in February 1951 to the Royal Society Computing Machine Laboratory at Manchester University.

Perhaps of greater marketing significance was the delivery in June 1951 by Remington Rand of its universal automatic computer, or Univac I, to the U. S. Census Bureau. The Univac I was a serial synchronous machine that operated at a 2.25-MHz rate and contained some 5,000 vacuum tubes. The computer could store 1,000 12-digit decimal numbers in its 100 mercury delay lines, while 12 additional delay lines operated as input/output registers. The instruction set comprised 45 distinct instructions, consisting of one-alphabet-character operation code and a three-decimal-digit address. Addition took 0.5 ms and multiplication 2.5 ms. Console switches and an electric typewriter were primary input/output devices, but most significant was the use of a metal-based magnetic tape—the first adaptation of that technology to data processing.

The Univac division of Remington Rand surged to public attention in the presidential election of 1952, when CBS-TV used the Univac I to predict Gen. Dwight D. Eisenhower's election shortly after the polls had closed on Election Day.

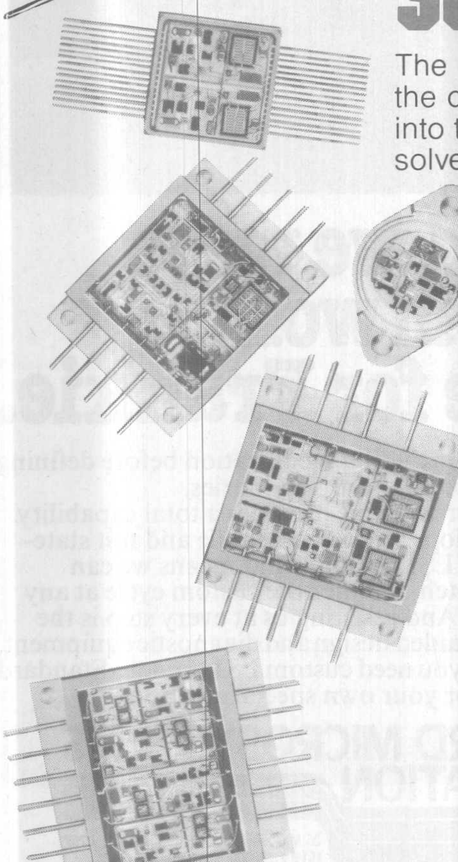
Univac was also responsible for many of the early technological innovations in computers. For example, the transition to the more powerful magnetic-core memory was swift once it was used in 1952 in the model 1103, designed by Univac's newly acquired company, Engineering Research Associates. The 1103 was some 50 times faster than the Univac I.

Univac led the industry in moving away from the vacuum tubes towards solid-state devices in computers. The company also advanced the concept of a special executive, or operating system software, for controlling the computer in 1960 when it introduced the Univac III. The machine was described as nine times faster than Univac II, and it offered concurrent programming. And just as the Univac division had pioneered in core memory technology with its 1103, it introduced in 1960 the 1107, which was the first computer to use thin-film memory as its control store.

Among IBM's earliest efforts was the Selective Sequence Electronic Calculator, unveiled at its New York headquarters in 1948. A hybrid machine consisting of 21,400 electromechanical relays and some 12,500 vacuum tubes, it could add 3,500 19-digit numbers a second. But it wasn't until 1952 that IBM introduced its first production electronic computer—the scientifically oriented 701.

First installed in IBM's New York City headquarters, the parallel synchronous 701 employed 4,000 vacuum tubes and 12,000 germanium diodes and had a master clock frequency of 1 MHz. Working with 36-bit words, the machine could perform 16,000 additions or subtractions per second (62.5 μs each) or 2,000 multiplications per second (50 ms each). With Williams storage tube technology licensed from Manchester University, IBM used 72 tubes that each stored 1,024 bits to build a 2,048-word memory with a 12-μs memory cycle. Punched cards provided input and output, and also available were a 150-line-per-minute alphanumeric printer and a magnetic-tape driver that stored 100 bits per inch.

IBM followed the 701 with the 702, and by 1954 it had replaced the 701 and the 702 with the faster 704 and



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Early biggie. One of IBM's earliest entries into the computer field was the Selective Sequence Electronic Calculator (SSEC), a hybrid machine shown here at IBM's New York headquarters in 1948. It used 21,000 relays and about 13,000 vacuum tubes.

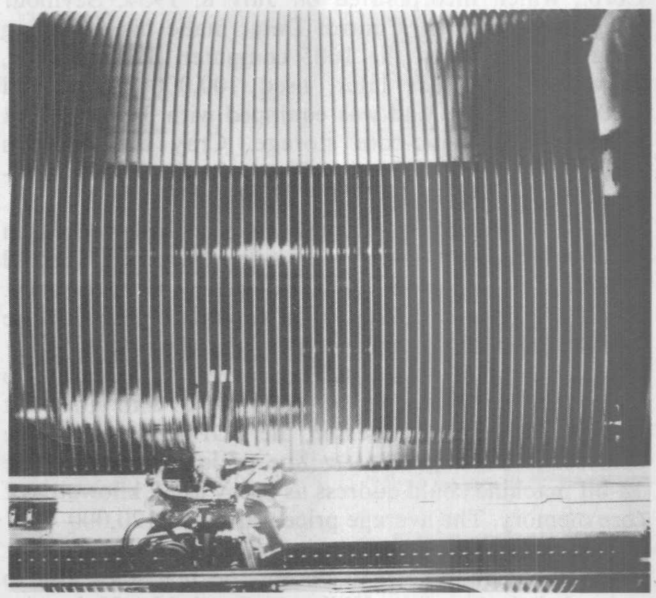
705. Both featured faster magnetic-core memory.

A revolutionary disk-storage unit came with the IBM 305 and 650 Ramac machines. Developed at the company's branch in San Jose, Calif., the Ramac had a stack of 50 magnetically coated metal disks that spun at 1,200 revolutions per minute. The surface of the disk could hold 100 tracks of data, each storing 10,000 characters. A single read/write head moved to the desired disk in the stack, then to the desired memory track on that disk—a procedure described at that time as analogous to that used by the single tone arm on a juke box.

IBM joined the switch to transistor logic circuits in 1958 with the introduction of its top-of-the-line 7090 computer. And one of the most successful computers IBM introduced was the transistorized model 1401. Unveiled in 1959, it became one the most widely used computers in the world.

Besides IBM and Remington Rand, National Cash Register and Burroughs were among office equipment makers who went into computer making in the early 1950s. By the middle of the decade they were joined by a host of electrical machinery and electronics concerns, such as General Electric, the Radio Corp. of America, Philco, and Honeywell.

GE, which had been manufacturing the electronics for NCR's operation, began marketing its own computer in 1960. It had opened a computer department in 1955 in Phoenix, Ariz., to produce a system called Erma (Electronic Recording Method of Accounting) for the Bank of America in California. Erma, developed by the Stanford Research Institute, used 12 tape drives and two drum memories, as well as a processor that contained 8,000 tubes. The first computer that GE put on the market, the GE 210, was an outgrowth of the Erma project.



Juke-box memory. Considered revolutionary when introduced was this disk-storage unit designed for the IBM 305 and 650 Ramac machines. It comprised 50 magnetically coated spinning disks. Each disk had 100 data tracks, each storing 10,000 characters.

RCA started with the design of storage cathode-ray tubes. In 1952 it introduced the Bizmac, a very large-scale data-processing system based on storage tubes and magnetic-tape storage. The machine was one of the first variable-word-length computers.

RCA's commercial computer effort began in 1958 with the introduction of the model 501. Two years later the company unveiled its 301 and 601 computers, featuring a juke-box type of disk memory that was similar to the one used in IBM's earlier Ramac.

Toward the end of the 1950s several companies were

Show Bizmac. RCA's entry in the computer field was Bizmac, claimed by the company to be the world's largest data-processing system at the time. This installation was shown at the Army Ordnance Tank Automotive Command in Detroit in 1957.

formed solely to manufacture computers. William C. Norris was elected president of the new Control Data Corp., which incorporated on July 8, 1957. Seymour Cray, a founder of Control Data, made his designing debut in 1956 with the 1605 computer. The machine, delivered two years later, used 100,000 diodes and 25,000 transistors and was equipped with 32,768 48-bit words of magnetic-core storage. Cray designed his second machine for Control Data, the desk-sized solid-state 160, in 1959.

In Maynard, Mass., Ken Olsen, who had worked on Whirlwind at MIT, joined his brother Stan and Harland Anderson to begin the Digital Equipment Corp. on Aug. 23, 1957. They had $70,000 in capital to manufacture basic digital logic circuit modules.

In 1959 the small Digital Equipment Corp. began to lower the price range of computers with its first Programmed Data Processor, the PDP-1. Based on the company's existing 10-MHz line of logic modules, the 18-bit machine could address as many as 32 kilowords of core memory. The average price was only $120,000.

With computers proliferating, designers searched for better techniques both to design the machines and to write their instructions. Wilkes at Cambridge University published two pioneering works in 1951 that helped in both areas.

With two co-workers, David J. Wheeler and Stanley Gill, he wrote the first programming text, "The Preparation of Programs for an Electronic Digital Computer," and at a computer conference at Manchester University in July 1951, he presented a paper, "The Best Way to Design an Automatic Calculating Machine." The design method he proposed became the basis for the microprogramming techniques that were to become popular two decades later, in the 1970s.

Univac, with the largest number of users in the early 1950s, led in making the machines easier to program. Early programming had involved coding in so-called machine language—strings of 1s and 0s whose pattern resembled hieroglyphics. Univac offered first, in October 1952, the more algebraic Short Code, which was interpreted by the machine line by line as it executed the program. But of more importance was the A-0 compiler developed by Grace Hopper for Univac.

This compiler took the entire program, written in easier-to-understand algebraic notation, and translated or compiled it at one time into machine language. The computer was then given the completely translated program to execute.

IBM's attempt to help users of its early 701 resulted in the Speedcoding System, released in 1953. But between 1956 and 1957 IBM put the finishing touches on a more significant programming aid—its Formula Translation method for programming computers, better known as Fortran.

Written by John Backus and by Irving Ziller for IBM's 704 computer, the software allowed the use of familiar algebraic notation. One of the most sophisticated programming languages around at the time, Fortran encouraged the use of computers. Univac also introduced its English language–like Flowmatic programming compiler that year.

One problem plaguing the computer industry at the end of the 1950s was the lack of standard programming languages. By design, every computer had its own machine language. One attempt to topple this tower of Babel was Algol, which stands for algorithmic language. It was developed jointly in 1959 by the Association for Computing Machinery and the German Association for Applied Mathematics.

In May 1959, the Pentagon also moved to establish a common programming language. A committee led by Grace Hopper, then a Navy captain, took just about a year to publish the Common Business Oriented Language, better known as Cobol.

By 1959 a number of applications were encouraging the use of computers. As the Bank of America had shown earlier, the processing requirements of the banking industry could easily justify the expense of computing equipment. Another application perfect for the computer was airline reservations.

In mid-1960 *Electronics* reported that the U.S. computer industry had installed 100 large computer systems that year, bringing the total to 600; 200 medium-scale machines for a total of 800; and 400 small-scale units for a total of 3,000.

The industry was looking forward to a dynamic future. At the Eastern Joint Computer Conference that year, a paper predicted that "miniaturization will allow vast amounts of available electronic storage, and this will drastically alter programming methods."

The greatest international cooperative research effort in history began on July 1, 1957, when researchers in 66 countries undertook simultaneous scientific probings of the earth and its environment. The investigation, called the International Geophysical Year, ended Dec. 31, 1958. Its primary objective was to gather data in three general areas:

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The last two areas were the most important to communications engineers. Much was learned about the effect of atmospheric absorption and reradiation of rf energy, clarifying the refraction principle that had been so useful in surface communications. A comprehensive study of atmospheric noise showed that the highest levels were over land in tropical regions, with rapid diminution above 50° latitude, whether south or north. It was also determined that because of ionospheric shielding a receiver placed in space would experience less noise from ground-based transmitters than would a receiver placed on the ground.

A high correlation was found between the sun's activity and variations in many earth phenomena, such as magnetism and auroras. And a more complete understanding was gained of the charged-particle energy-exchange process in the ionosphere. The mystery of the Faraday effect—the previously known pattern of rf signal fading—was solved: it was found to be due to the steady rotation of the polarization of signals under the influence of the earth's magnetic field.

The Explorer satellites launched during this time led to the discovery of the Van Allen radiation belts, and more was found of the origins of cosmic noise. These discoveries helped scientists speculate further on the beginnings of earth and the universe.

The dramatic news in space, though, was being made in conjunction with rocketry. The Soviet Union had electrified the world by launching Sputnik I into orbit around the earth. The announcement came on Oct. 4, 1957, while an American Vanguard rocket was on the launch pad at Cape Canaveral, Fla., going through a checkout before attempting the same orbital feat.

Not only had the Russians been first, but their Sputnik also weighed an impressive 183 lb against Vanguard's initial 4 lb. Later Vanguard satellites reached 22 lb—still far from Sputnik's weight.

Americans were still in turmoil over the Russian success when the Soviet Union less than a month later, on Nov. 3, launched the 1,100-lb Sputnik II carrying a dog as a passenger. The United States had lost the first heats of the space race by default. On paper, the U. S. had a significant advantage, with studies by Government laboratories to lean on and Robert H. Goddard's pioneering work in rocketry in the 1920s. Perhaps most important, it had the premier German rocket team of Wernher von Braun and some 60 of Germany's V-2 rockets captured at the end of World War II.

After the shock of Sputnik, the Navy attempted on Dec. 6, 1957, to orbit a Vanguard payload, but the first stage failed after the rocket rose 3 feet from the pad. Vanguard burst into flames.

Meanwhile the White House had authorized the von Braun team at the Army Ballistic Missile Agency to launch its Explorer-Jupiter combination. American prestige was partly redeemed by the successful launching of the 31-lb Explorer I on Jan. 31, 1958, but the U. S. was clearly behind and more embarrassment lay ahead.

In the summer of 1958 it had become clear that a single agency would have to pull together the scattered space efforts if the U. S. were to match the Russian successes. Although the Pentagon was the logical choice and the Atomic Energy Commission was making a strong case based on its work with nuclear warheads, President Dwight D. Eisenhower preferred a civilian agency for diplomatic purposes.

The decision, backed by Senate Majority Leader Lyndon B. Johnson, was to use the relatively obscure National Advisory Committee for Aeronautics as the nucleus of the new agency. Established during World War I as the focal point of the nation's aeronautical research, this body already had major wind tunnels, laboratories, and even a rocket-launching facility. All it needed was sufficient money and a space project.

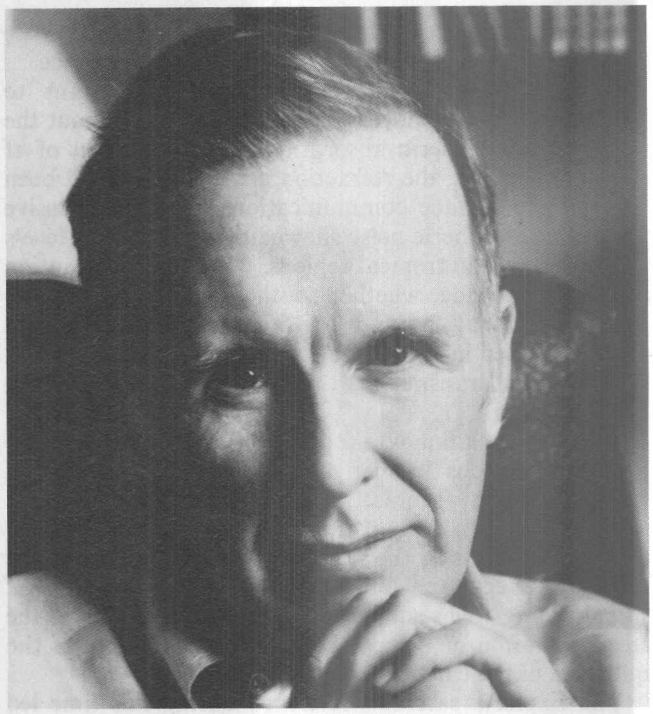
The National Aeronautics and Space Act, signed into law July 29, 1958, gave the agency both. The new agency, the National Aeronautics and Space Administration, opened its doors Oct. 1 that year with the Navy's 150-man Vanguard team, 8,000 people of its own, $300 million worth of facilities, a budget of $100 million a year, and another $100 million of unspent Defense Department funds. A week later, NASA's first administrator, Thomas Keith Glennan, a former commissioner of the Atomic Energy Commission and former president of Case Institute of Technology, gave the go-ahead for project Mercury. The goal: put a man in space. The job was assigned to a space task group headed by Robert R. Gilruth at the Langley Center near Hampton, Va.

But NASA still had to wrest the von Braun team from the Army to have a viable space program. After a good

Design whiz. One of the founders of Control Data Corp., Seymour Cray (left) established his reputation for innovative design with the all-solid-state 1605 computer, which made its debut in 1956. Cray followed this with the desk-sized 160 three years later.

Programming guru. Two pioneering works by E. V. Wilkes (right) of Cambridge University helped advance computer design and use. With two associates he wrote the first book on programming principles, later proposing a design technique that is basic to modern-day microprogramming.

Captain of industry. A major development in the programming art was the A-0 compiler developed for Univac by Grace Hopper. Later, as a Navy captain, she headed a committee that developed the Common Business Oriented Language—better known as Cobol.



Father of Fortran. The Formula Translation method of programming, more familiarly known as Fortran, was written by IBM's John Backus (above) and Irving Ziller for the 704 computer. Its familiar algebraic notation encouraged the proliferation of computer use.

deal of political logrolling this was accomplished in two steps. First, the Army's Jet Propulsion Laboratory at Pasadena was transferred to NASA sponsorship in December 1958. Then the Army Ballistic Missile Agency at Huntsville, Ala. (with von Braun's Saturn booster program), was shifted to NASA control in March 1960. With this nucleus in place, NASA proceeded to build facilities of its own at the Cape Canaveral launching area and at the Goddard Center in Greenbelt, Md.

NASA's biggest problem in its first two years was to develop reliable launch vehicles. Seven of 17 launched failed in 1959, but finally in August 1959 NASA launched its first fully functioning satellite, Explorer VI, and the U. S. space effort was headed for supremacy.

While American attention was focused on the more sensational aspects of space exploration—putting a man on the moon—communications researchers weighed other values.

Earth satellites, they knew, had several important characteristics for communications. One was the availability of bandwidths far exceeding anything otherwise available. For example, transatlantic television transmission could take place only after a satellite for this purpose had been placed in orbit; it could not be done with transatlantic underwater cables. The satellite concept enabled the globe to be covered without the major disadvantage of wire hookup.

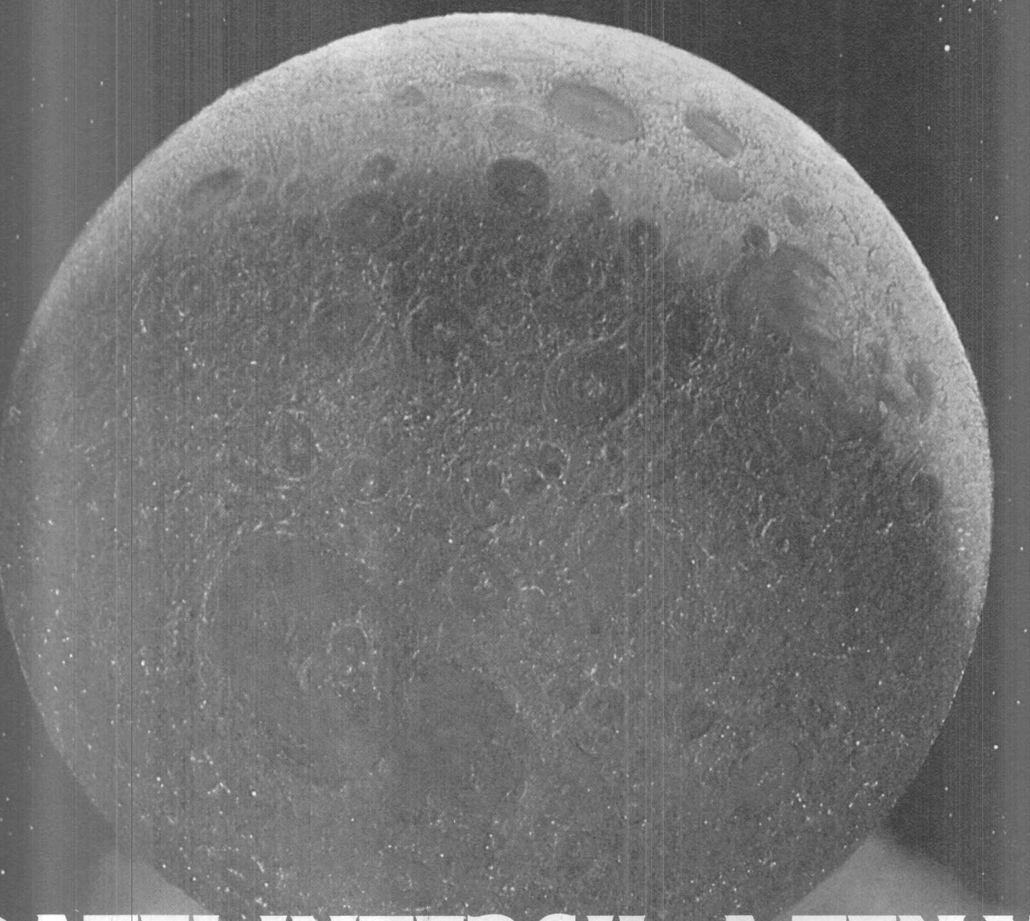
Meanwhile there were major leaps forward in communications theory. In a pioneering paper in the Bell System Technical Journal, a Bell Laboratories scientist, Claude E. Shannon, had introduced in 1948 a numerical measure of the randomness, or uncertainty, with which a message arrived at its destination correctly. He called it entropy, a new use of the thermodynamic term for the level of randomness in matter.

Shannon showed that entropy measures, in a practical way, just how sophisticated a communication facility must be to transmit usable messages, whether by television, radar, or other means. What's more, he proved that this sophistication could be predetermined as a function of the accuracy of the communication system, or the level of errors that could be allowed in the system.

As Shannon himself said in an article in *Electronics* in April 1950: "The newer systems of modulation, such as fm, pulse-position modulation, and pulse-code modulation, have the interesting property that it is possible to exchange bandwidth for signal-to-noise ratio; that is, we can transmit the same information with a smaller transmitter power, provided we are willing to use a larger bandwidth. Conversely, in pulse-code modulation, it is possible to use a smaller bandwidth at the expense of an increased signal power. The discovery of these systems has prompted a re-examination of the foundations of communications theory."

Shannon's work and its later developments became known as information theory. It was put down in great detail by Shannon and a colleague, Warren Weaver, in their book "The Mathematical Theory of Communication," published by the University of Illinois Press in Urbana in 1949.

From then on, all of the system parameters of interest in any electronic communication could be related to one another. These included signal-to-noise ratio, bandwidth, modulation rate, power, and others. In the main,



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Shannon's theories provided upper bounds on just how efficient a system could be.

The successful use of the maser (which stands for microwave amplification by stimulated emission of radiation) represented a breakthrough in low-noise amplification at microwave frequencies. This amplifier, which had to operate at liquid-helium temperatures, enabled engineers to construct a receiver with no more self-generated noise than that produced by the antenna and transmission line connected to it.

The maser was a byproduct of basic research on microwave absorption by paramagnetic materials cooled to a temperature near absolute zero. Like all amplifiers, the maser depended on control and conversion of energy from one form into a more useful form.

The first clear recognition of the possibility of amplification of electromagnetic radiation by stimulated emission appears to have been made by a Russian, V. A. Fabrikant. He filed for a Soviet patent in 1951, although it was not published in Russia until 1959. In fact, Fabrikant had written about parts of this theory in 1940 and had tried but failed to produce amplification in cesium gas.

Several proposals for masers of various types appeared in American physics journals in the early 1950s. But the real breakthrough and excitement was caused by a short article by James P. Gordon, Herbert J. Zeiger, and Charles H. Townes in 1954. In this seminal paper, they announced that they had indeed made a maser operate in 1954 by using ammonia gas as the active medium. Contributing to their success were Townes's earlier experiments in microwave spectroscopy—the study of microwave absorption in materials.

In later years many other maser methods were tried, including two-level and three-level techniques. But the one with the most practical results was a three-level approach. Here the excited atoms were put through three changes in internal energy to produce the maser amplification action. This maser amplifier was devised by Nicolas Bloembergen, a physics professor at Harvard University, and was the workhorse of the field for many years. By actual measurement, the noise figure of a maser was just over 1 dB, near the ultimate of 0 dB.

A problem with the maser was its inherently limited bandwidth—a couple of hundred megahertz at best. It was difficult to make it more broadband; still worse, the maser had to be operated at liquid-helium temperatures, or about 4° above absolute zero. The expensive and inconvenient refrigerators this required were not suitable for practical communications systems.

But the maser did make a major contribution to communicaton technology: extension of its concept led to the development of the optical amplifier, or laser.

The maser and laser principles were similar, but the operating wavelengths differed. In 1977, the U.S. Patent and Trademark Office granted a patent covering "optically pumped laser amplifiers" to physicist R. Gordon Gould after a long legal struggle based on one of Gould's notebooks notarized Nov. 13, 1957. But the laser was developed independently in 1958 by Townes, working with Arthur L. Schawlow at Bell Telephone Laboratories. They said it might be possible to cause vapors of the element potassium to show laser action.

Laser "action" meant that under proper stimulation, the vapor would give off an intense beam of coherent light. A laser beam, it was realized, was ideal for a communication system because of the large amount of information that could be modulated onto it without disturbing its coherent characteristics. Moreover, such a source of energy opened up previously unused regions of the electromagnetic spectrum, and the spectrum appeared destined to be in short supply, if the world's information needs grew as predicted.

The first solid-state laser action was achieved in synthetic ruby, though the ruby available at the time was originally thought to be too poor to give satisfactory results. It was a surprise, therefore, when Theodore Maiman of Hughes Aircraft's Research Laboratory achieved laser action with it in 1960. In 1961, only a few months after this success, the first working gas laser, using a mixture of helium and neon, was announced by Bell Labs. The laser age was now in full swing.

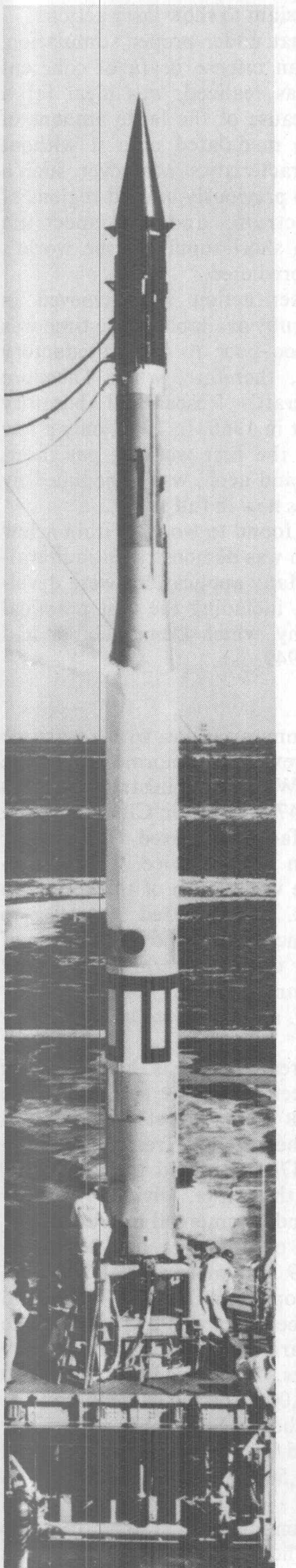
Later, cesium vapor was found to work. Within a few years successful laser action was demonstrated in literally hundreds of materials. Many applications were developed over the next decade, including the first practical demonstration of holography, which Dennis Gabor had enunciated in principle in 1949.

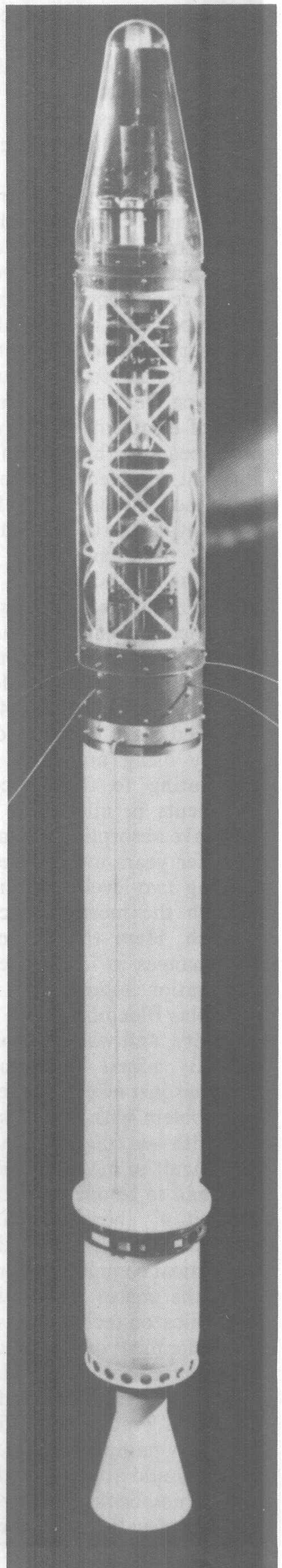
Radio communications, with a wartime of experience to draw on, expanded enormously in the civilian sector. When the World Administrative Radio Conference convened in 1947 in Atlantic City, N. J., the 78 countries represented faced increased demand for communication channels in every service. The conference undertook to open the vast region of the spectrum from 300 MHz to 10 GHz. It designated 300 MHz to 3 GHz the ultrahigh-frequency region and the balance of the spectrum the low end of the superhigh-frequency region. The space accommodated experimental TV systems, navigational radar, and common-carrier microwave relays.

In June 1949, the FCC created citizens' band radio in the U. S., with operator licenses for the asking. Unlike amateur radio operators, CB users did not need personal technical qualifications. The original frequencies allocated to CB were 460 to 470 MHz, and there were 41 stations in 20 states at the onset, divided between hobbyists, experimenters, and commercial interests.

Civilian communication of all types had so mushroomed by the end of 1959 that more than 1.7 million transmitters were being operated in the U. S. and 570,000 radio stations had been licensed by the FCC. The stations included 92,000 marine, 81,700 aviation, 81,000 land transportation services, 55,000 industrial, 31,000 public safety and almost 60,000 Class D citizens' band at 27 MHz, a category established in September 1958. Only 5,000 of all the licenses had been issued for commercial broadcast stations—some 3,500 for a-m, 825 for fm, and 672 for TV.

Civilian aviation and communications growth were inextricably intertwined. Though in wartime thousands of aircraft were allowed to roar off relatively uncon-





Embarrassment. America's shock at the Soviet launching of Sputnik in October 1957 was compounded by the failure of the Navy's Vanguard rocket on the launching pad two months later. More than a year later Explorer I recovered some U. S. prestige.

Redeemer. Explorer I, a model of which is at right, was placed in orbit on Jan. 31, 1958, launched by a Jupiter C rocket from Cape Canaveral. The 18-lb satellite discovered the first of the radiation belts around the earth now known as the Van Allen belts.

trolled into the "wild blue yonder," civilian planes depended on reliable electronics for safe operation.

After World War II both commercial and private flying increased rapidly, and air traffic control became a matter of concern. A national network of traffic control centers had been started by the Federal government in 1936. By 1941 there were 15 such centers run by the Civil Aeronautics Authority, a predecessor of today's Federal Aviation Administration.

A vhf omnidirectional radio (VOR) airway system and distance-measuring equipment (DME) were suggested in 1948 by the Radio Technical Commission on Aeronautics, a group of industry and Government experts in aeronautical telecommunications. These recommendations came after a study of air traffic control.

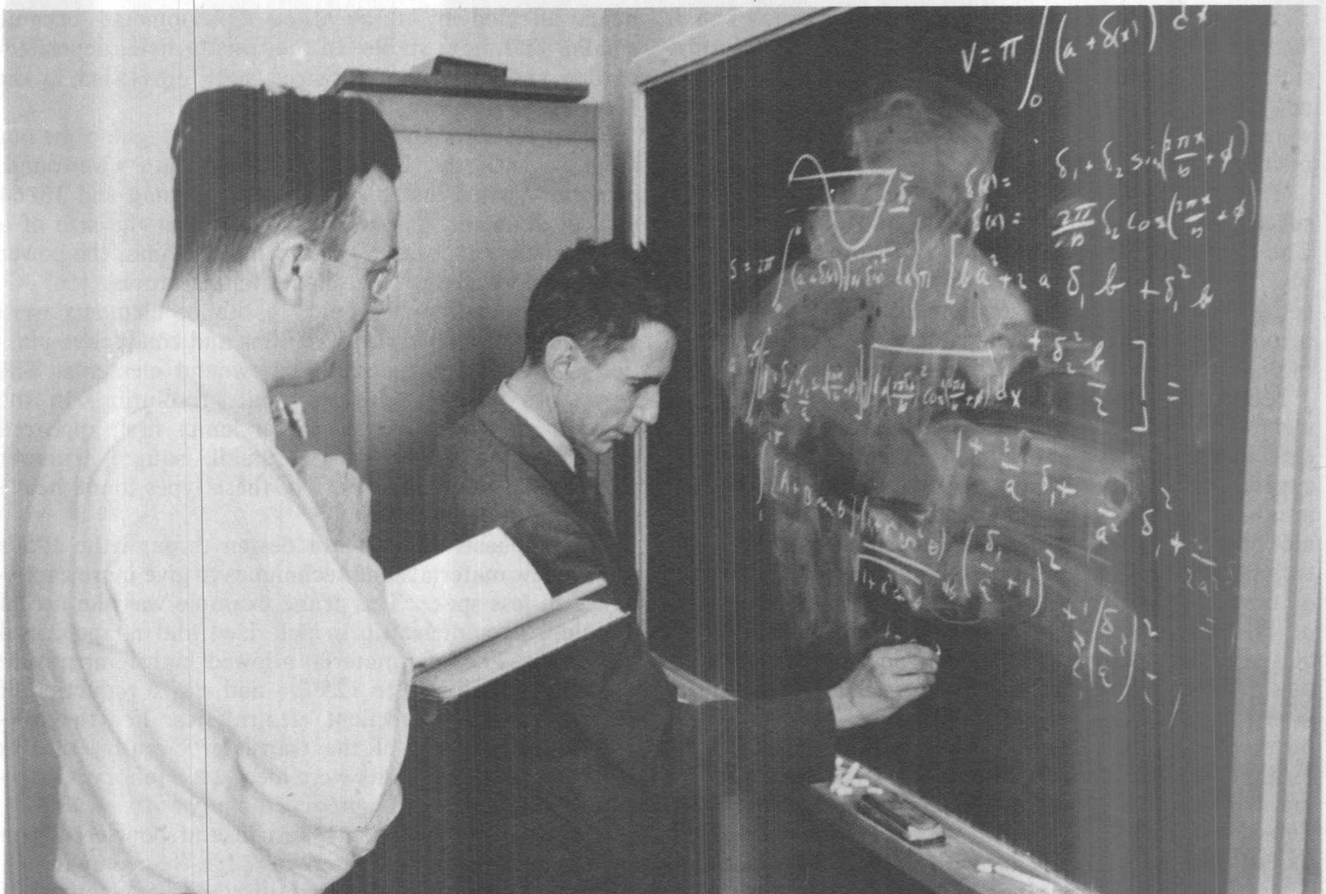
By October 1950 there were 271 VOR stations, and the first VOR airways were commissioned; they linked Kansas City; Denver; Albuquerque, N. M.; El Paso, Texas; Omaha, Neb.; and Oklahoma City in a 4,380-mile network. By 1952 the network extended to 45,000 miles, and the CAA had begun to decommission earlier low-frequency radio-range stations.

Increasing air traffic continued to demand expansion of the available radio frequencies, and in 1957 the CAA began to change to narrow-band equipment that doubled the channels for vhf communications by reducing the spectrum used from 200 kHz to 100 kHz per channel.

Congress, spurred to action by a midair collision of two airliners over the Grand Canyon in June 1956 and two midair collisions of military and civil aircraft in the spring of 1958, finally passed the Federal Aviation Act of 1958. This repealed all the previous aviation legislation and redistributed all the functions to two independent agencies: the Civil Aeronautics Board, with responsibility for economic regulation of air carriers and for accident investigations, and the FAA, with sole responsibility for managing the nation's airspace.

One immediate development was the use of automation in the ground-based phase of air traffic control. Commercial Univac computers introduced in 1956 were installed between 1959 and 1961 at the air route traffic control centers (ARTCCs) in New York, Washington, Pittsburgh, Cleveland, and Boston to prepare flight progress strips that previously had been prepared by hand and to exchange information between centers.

For components, the years 1947 to 1960 were memorable. In addition to the invention of the transistor, there were other important events and trends that also helped shape present-day electronics. They included:



Enter entropy. Bell Telephone Laboratories scientist Claude E. Shannon, at the blackboard, wrote the landmark work on information theory. Using entropy as a basis of measurement, it helped define the limits and relate all the parameters of communication systems.

- Miniaturized packaging methods, micromodules, thin films and the start of the integrated circuit.
- The emergence of etched printed-circuit boards.
- High-density wiring with wirewrapping techniques.
- Automatic insertion of parts into pc boards.
- Fully automated television and radio assembly lines.
- Advances in miniaturized passive components.

In addition there were interesting developments in miniature ceramic tubes, but they came too late. They were superseded by transistor technology.

Screened and fired thick-film conductors and resistors on steatite substrates had been used in World War II in the electronic portion of the proximity fuze. After the war, the company that had introduced these devices, the Centralab division of Globe Union Inc., applied thick films commercially, calling its modules "packaged electronic circuits," or PECs. They were quite successful, as the thick-film technique lent itself to automation.

The circuitry in a PEC in 1949 ranged from simple RC coupling and filter networks to binary counters and complete hearing-aid and telephone amplifiers. Centralab still builds PECs, but transistors and diodes in tiny plastic packages replace the subminiature tubes. Hundreds of millions of PECs have been produced.

The war years had also seen the first attempts at potting modules and circuitry to protect them from the environment. The antiaircraft version of the proximity fuze, for example, was sealed in wax. In the late 1940s, a few concerns embedded objects in Lucite and Plexiglass, but this technique was discarded because of the poor electrical properties of the materials. Then, in June 1950, William R. Cuming of Emerson Cuming in Boston discussed the first of the polystyrene cast resins. It had a low dissipation factor and dielectric constant, along with excellent mechanical and environmental properties, and it became a heavily used potting material.

In 1951, the National Bureau of Standards, under Navy sponsorship, initiated a three-dimensional packaging scheme called Project Tinkertoy. The process, which had a component packaging density of 10,000 parts per cubic foot, lent itself to automation.

The building block of Tinkertoy was a steatite wafer ⅞ inch square by 1/16 inch thick. Components, screened or discrete, were mounted onto screened and fired silver conductor patterns on the wafers. Each had 12 notches with conductive paint in them. About four to eight of the wafers with different components were automatically selected, stacked, and joined mechanically and electrically by machine-soldered riser wires to form a standard module with a tube socket on the top wafer. Each wafer had one to four components.

This method was used by Sanders Associates to produce Navy sonobuoys, but in 1957 a new system—the Signal Corps/RCA micromodule program—made Project Tinkertoy obsolete. RCA engineers concluded that a system based on a smaller, thinner wafer could give them

a parts density 50 times greater than Tinkertoy could. The basic block was a square ceramic wafer, 31 mils on a side and 10 mils thick, with 12 conductively coated notches. The wafers, usually with a single component, were called microelements and were stacked into micromodules, then potted and plugged into a pc board.

These modules, using transistorized circuitry, were successfully designed for rf audio and digital circuits. The micromodular equipment, with automated assembly, cost about one and a half to two times less than conventionally assembled equipment. The micromodule involved more than 40 companies and cost over $15 million. It was made obsolete by the integrated circuit.

Miniaturization advanced in 1959 with the development of the thin-film hybrid at Bell Telephone Laboratories. In this method, thin-film conductors, resistors and capacitors, all of tantalum, were sputtered in high vacuum onto a glass or ceramic substrate. By 1960 companies like Varo and IBM were experimenting with the technique. Varo was putting down lumped RC networks onto ceramic substrates. IBM was evaporating thin films of Nichrome, silicon dioxide, and aluminum onto a glass substrate 0.7 inch on a side. Seventeen successive masks were used to form conductors, resistors, and insulating layers. Bare transistor chips were compression-bonded on.

While the packaging of electronic circuitry was evolving from the thick films of World War II to thin films, the etched printed circuit was beginning steady growth to become the preeminent method of interconnection. There had been many false starts. In 1949, however, the Army Signal Research and Development Laboratory at Fort Monmouth, N. J., announced the development of dip-solderable etched pc boards.

In 1950, Powers Chemco started a small pc laboratory under Robert Swigget to investigate the possibilities of manufacturing pc boards with the Signal Corps process. In 1951 the Photocircuits Corp. was formed on Long Island in New York State, and the independent pc industry began.

From this time to 1960, pc technology evolved gradually, with plated through-holes appearing in 1953, glass-epoxy copper-clad laminates in 1952, solder masks in 1955, and the multilayer board concept in 1960.

A parallel development with the rise of printed circuitry was the automatic assembly of standard leaded parts into pc boards. In September 1954 United Shoe Manufacturing came out with a machine that could insert parts so fast that 100 boards could be completed in an hour. The unit was capable of inserting axial resistors or jumpers. In March 1955 General Mills built a 24-head automatic insertion system for IBM.

Another form of automation was introduced by R. F. Mallina of Western Electric in 1953—wirewrapping of insulated wire around square pins. This solderless, fully or semiautomatic wiring method is still in heavy use today, particularly in computers and other data-processing equipment.

And while packaging techniques, printed circuits, and automation were speeding ahead, the passive components affected by these three developments became smaller and more stable. In the resistor field, deposited-carbon and metal-film resistors, both developed in the 1950s, gave better temperature stability.

Power resistors, too, were changing. Sprague came out in 1954 with the Blue Jacket, a 3-watt wirewound, porcelain-coated unit about 35/64 inch long and 13/64 inch in diameter. These units were about the size of a 1-W carbon-composition type with three times the power rating and less derating at higher temperatures.

In the potentiometer field, resistance elements were made from deposited metallic films and conductive plastics, along with the normal wirewound elements. The new types gave essentially infinite resolution. In the trimmer field, small rectangular units first appeared about 1954–55, followed by small, square trimmer potentiometers in 1960. Both of these types found heavy use in military equipment.

The emphasis in capacitor design through the 1950s was on new materials and techniques to give more capacitance in less space. The prime example was the use of tantalum as a dielectric in polarized and nonpolarized capacitors. The new material allowed high-temperature operation—easily up to 125°C—and a size reduction of two thirds over equivalent electrolytics. For the low-voltage applications of the transistor circuitry of this time, the new small units were ideal. PR Mallory, General Electric, and Sprague produced many of them.

In magnetic components, ferrite and powdered iron cores in varied shapes were giving high-frequency inductors and transformers the versatility and compactness of low-frequency units. Toroidal construction was finding greater use, and metalized glass inductors were giving stability and ruggedness. By 1957 new wires, cores, and insulation were shrinking magnetic components.

In the relay field, the subminiature crystal-can relay made its first appearance in about 1954. The reed relay, developed at Bell Telephone Laboratories in 1950, also began to be used extensively.

Two developments in ceramic tubes were outstanding engineering feats in the 1950s, but both were quickly made obsolete by the transistor. In 1956, under a joint contract from the military and the Atomic Energy Commission, General Electric designed a group of components capable of withstanding temperatures in the 600°C range. One component was a tiny ceramic tube (about the size of a low-level cased transistor) that had no filament. At about 600°C and over, the tube's cathode would emit electrons.

In 1956 GE used these tubes to design and fabricate digital modules that operated at 580°C. About 0.32 inch in diameter and 0.36 inch high, these small units were known as thermionic integrated micromodules, or TIMMs. The circuits proved stable at high temperatures and were extremely radiation-tolerant.

In 1959 the RCA Nuvistor emerged. It was a ruggedized miniature ceramic tube with low power drain and increased performance at high frequency, as well as excellent reliability. The small tube had a pinned base and was aimed at both military and consumer uses, unlike the GE type.

Meanwhile the success of electronic industrial control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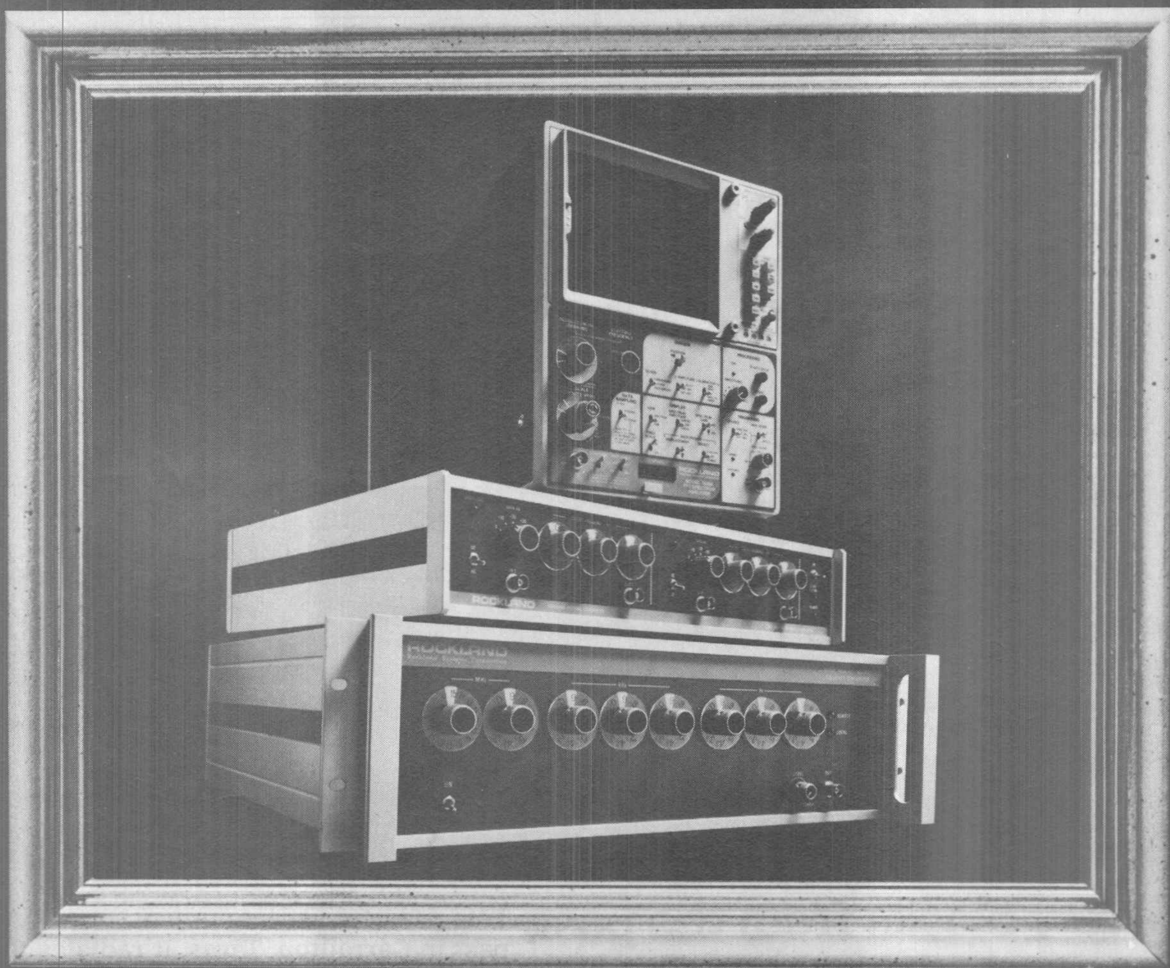

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By 1950 the chemical, petroleum, textile, pulp and paper, metal-working, and food industries all had experimented with new generations of electronic measurement and control hardware and even with automatic process-control systems. Those closed-loop systems took control completely out of the hands of the operator and gave rise to some workers' resistance to automation.

The equipment of the early 1950s was conceptually identical to today's hardware: transducers and circuits that measured physical quantities like length, mass, time, temperature, level, and pH; automatic controllers that compared the measured to the desired value of a variable and then took action to correct it; control-element drivers like diaphragm motors, electric motors, and solenoids; and recorders and indicators.

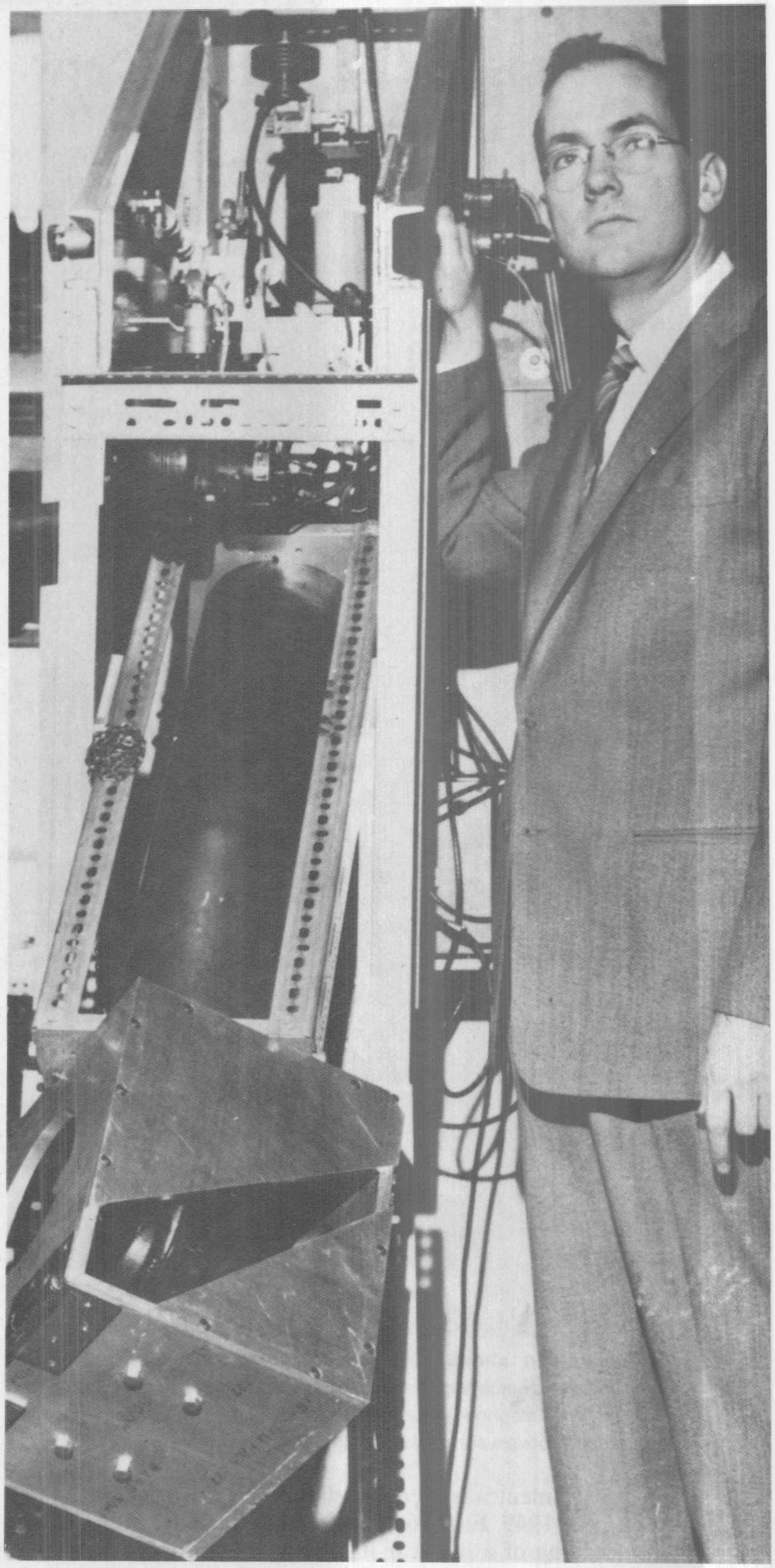
In the mid-1950s industry asked for even more sensitive and reliable instruments and control equipment, and electronics suppliers responded. Typical of the state of the art then was the range of instruments available to the oil industry in 1954. It included such aids to exploration as radiation-sensitive scintillation counters, gravity meters employing phototube amplifiers, seismographs, infrared analyzers, oscillograph recorders, and a full line of sensitive RC-coupled multistage amplifiers with miniature 12-V vacuum tubes.

At the same time industrial electronics assumed a slightly digital flavor. In 1956 at least 15 manufacturers, including Bendix, GE, and RCA, offered punched-card– or magnetic-tape–programmed milling machines to the metal-working industry. Some machines used multi-element tubes in digital configurations, among them multipliers and binary counters.

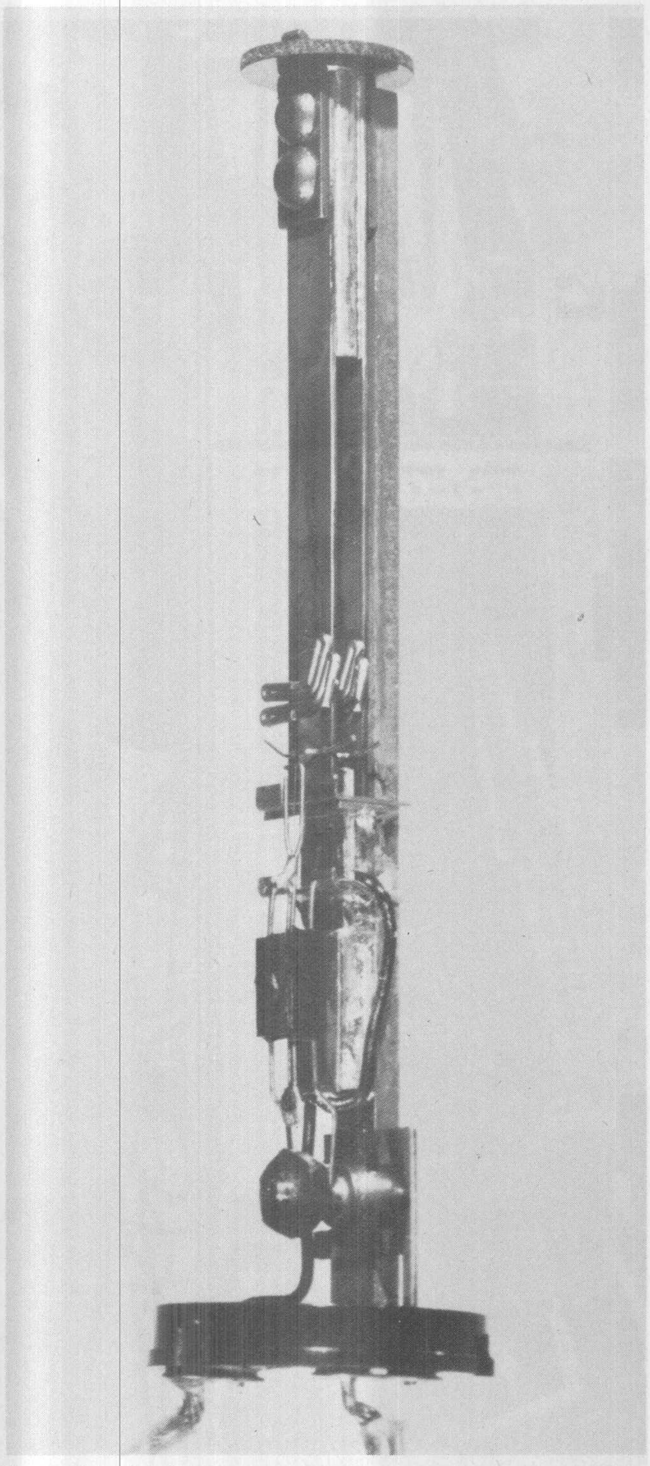
In the era opened by the invention of the transistor, instrument manufacturers were faced with demands for finer resolution, greater accuracy, and broader measurement capability.

The Government and industry were looking for new ways in which to use atomic energy, and they sought research tools to help them understand and apply the new power. In filling that demand, the instrument makers devised techniques that could be applied to frequency measurement as well. This was indeed fortunate, because increased use of the lower portion of the spectrum for radio and television broadcasting was necessitating finer measurement to prevent interference.

For atomic investigations a better way was needed to quantify the scintillations sensed by the Geiger-Muller tube. The Potter Instrument Co. found it in the 1944 invention of the counter circuit by its founder, John Potter (see Chapter 4). This had already proved its usefulness in early computers and in predetermined counters for measuring fixed amounts of discrete objects, such as resistors. In 1948, a four-decade version of the



Low noise. An early application of quantum mechanics to electronics was the maser, first proposed by a Russian and first built by Charles H. Townes (above) and associates in 1954. It was the forerunner of the laser for which Townes later shared the Nobel prize.



Magnetic shrink. The thrust toward miniaturization reached magnetic components such as crystal-can and reed relays developed at Bell Telephone Laboratories in 1950. By 1956, reed relays like those above were showing up in subscriber ringers.

instrument was used in radiation measurement.

In 1949 El-tronics found that it could simplify the reading of a count if it used a different type of circuit, the Higgenbotham, which provided an output directly in decimal notation rather than BCD. Then the Berkeley Instrument Co. realized that adding a time base to the counter would make it much easier to measure the half life of radioactive materials. With an internal interval timer, the instrument could automatically make the measurement for a known, fixed period, and from this the half life could be derived. The same instrument, researchers realized further, could also be used for time and frequency measurements. Result: the first universal counter was built.

Hewlett-Packard, on the other hand, concentrated on the application of these techniques directly to frequency measurement and in 1952 introduced the first instrument to bear the name frequency counter. It was the model 524A, and it was able to display frequencies up to 10 MHz. On an analog meter, frequencies of this range could be read directly only to within 100 kHz at best. But using the counter display, one could read 10 MHz with a resolution of 0.01 hertz.

The demand for radiation counters attracted Haydu Brothers (later to be known as Burroughs) in Plainfield, N. J. A manufacturer of cathode-ray and other types of electron tubes, it designed the Nixie tube in 1951. These gas-filled, cold-cathode tubes had 10 cathodes shaped as numerals 0 to 9. When addressed by applying a voltage between the anode and individual cathodes, the gas surrounding the selected cathode glowed, displaying the appropriate numeral in pleasing orange.

These tubes, in turn, caught the attention of an engineer named Andrew Kay. Using them, he built a digital meter that excited the cathodes by closing the contacts of telephone relay switches. The relays were set, depending on the voltage level presented to them, by a divider network with a dc voltage across it. Kay formed a company, Non-Linear Systems, to market the digital voltmeter, called the model 419, and in 1952 the first digital voltmeter was sold.

Because of the custom circuitry that went into these early DVMs, they were fairly expensive, as well as bulky. Yet the higher resolution they provided—to 4 digits—was needed in laboratories, and thus they found a narrow market. Not until the end of the decade, when digital computing became more firmly entrenched, was Kay's concept widely employed by the instrument industry.

The speed with which the fast-developing digital computers could solve complex equations presented another problem: how to capture and display the results of these computations. The teletypewriters of the time were not fast enough, and buffer memories had not been developed. The research for a suitable display not only provided a market for new instruments, but eventually it also resulted in new displays for instruments.

The cathode-ray tube had already proved its ability as a display device in oscilloscopes, radar, and television. It was a logical choice for computers. In February 1948, Harrison W. Fuller of Harvard University's Computer Laboratory described the development of the Numeroscope. Built under contract to the U. S. Navy's Bureau of Ordnance, this device electronically generated numbers on the face of the CRT under the control of a computer. It was the granddaddy of all CRT terminals and digital read-out oscilloscopes.

The Government's willingness to pay for the most sophisticated electronics led to measurement refinements throughout the industry and a demand for precise stan-

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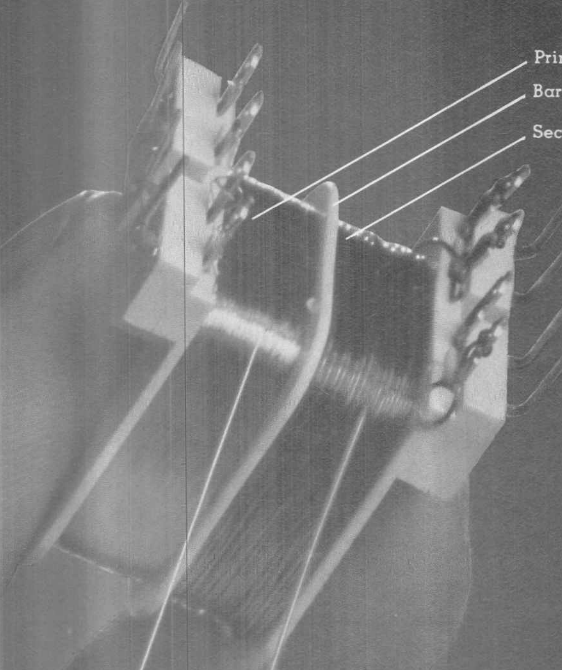

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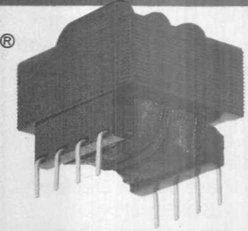

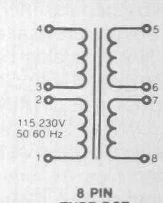

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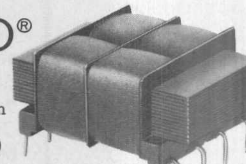

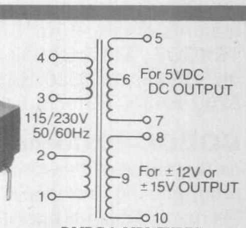

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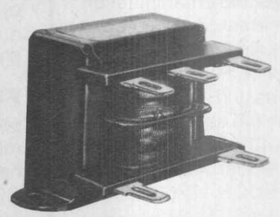

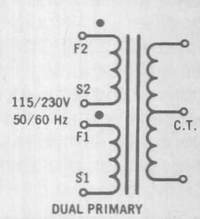

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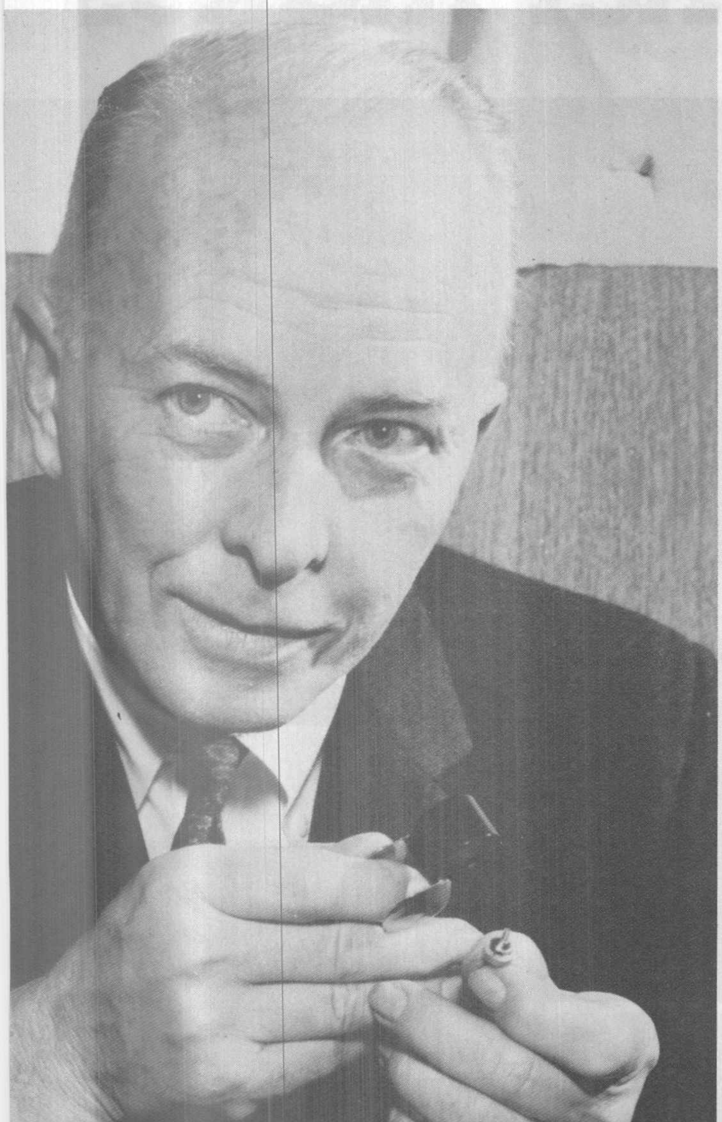


Next-to-last gasp. A strong attempt to stave off the threat of the transistor was made by RCA in introducing the Nuvistor, a miniature ceramic tube with low power drain and high reliability. Despite many merits, it failed to halt the inexorable march of solid-state devices.

dards. One manufacturer who benefited was John Fluke.

Fluke and a roommate at MIT, Art Anderson, had formed an engineering company in 1948 to produce power supplies and instruments. The company's first instrument was the model 101 VAW, a meter that electronically measured power at frequencies from 20 Hz to 200 kHz, as well as current and voltage. Shortly thereafter, the company discovered another lucrative market, nuclear research, and began to supply it with high-voltage dc power supplies.

In 1952, Anderson-Fluke Engineering moved to Seattle, Wash., and the following year incorporated under the name John Fluke Manufacturing, Anderson having left to pursue his civil engineering interests. Testing the power supplies, which were selling in volume, was proving to be an arduous task; an entire basement of batteries was needed to provide high voltages in order to prevent current flow from the supply under test. Patience was also required to allow the batteries to stabilize between measurements.

In 1955, one of the company's first employees, Robert Hammond, came up with a highly stable and accurate 500-V power supply. With a null meter and a bridge circuit, a user could find the difference between the reference voltage and the voltage of the supply being tested. A small box thus contained everything needed to test the supplies, and the box was called a differential voltmeter.

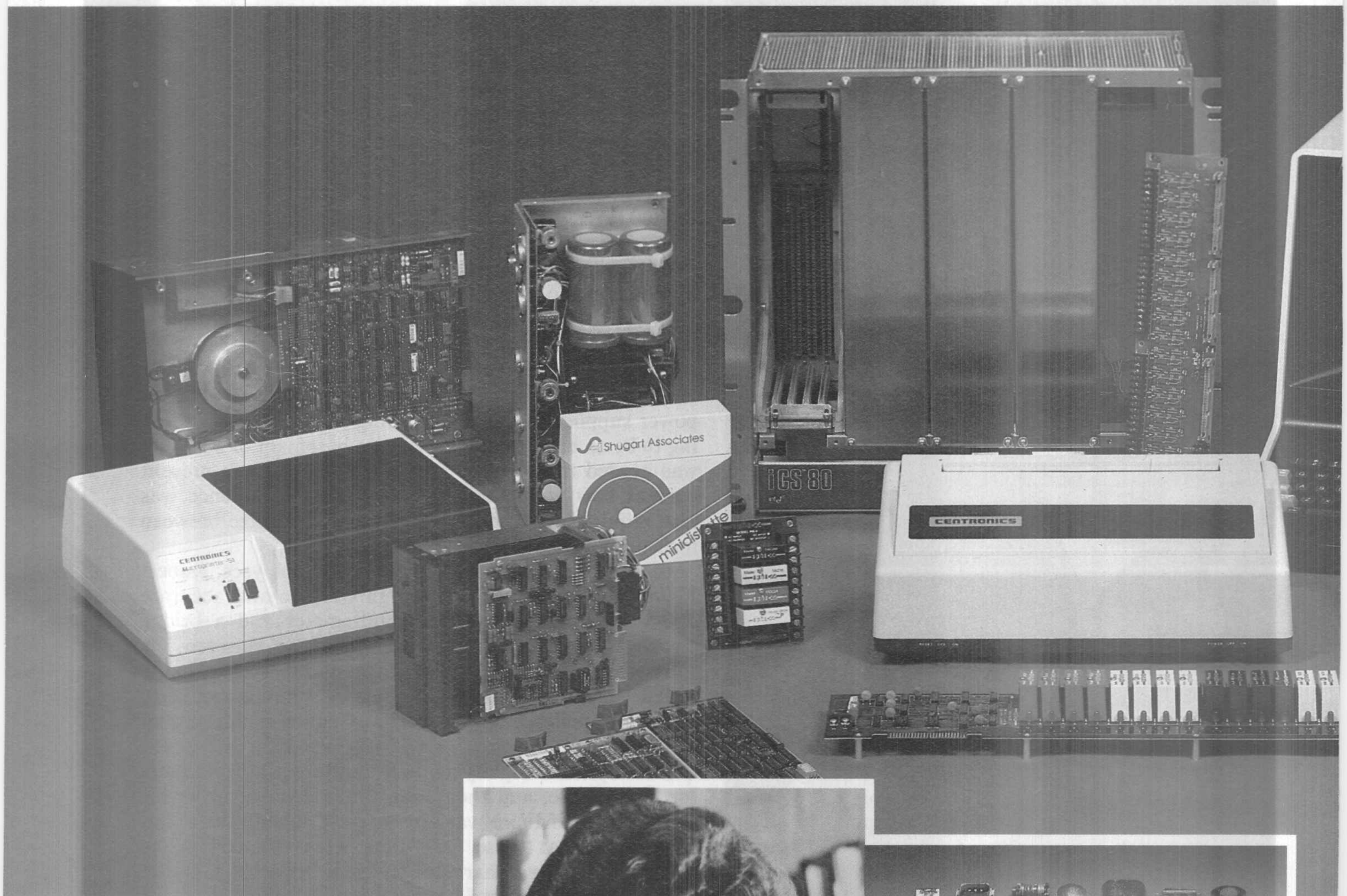
Initially the company made five differential voltmeters for its own use, and then John Fluke decided to let his salesmen see if there was any interest outside the plant. He recalls that these first units were snapped up so quickly that it was hard to get back his sales samples. Given model number 800, but familiarly known as the Flukemeter, it was responsible for doubling the gross of the young company that fiscal year.

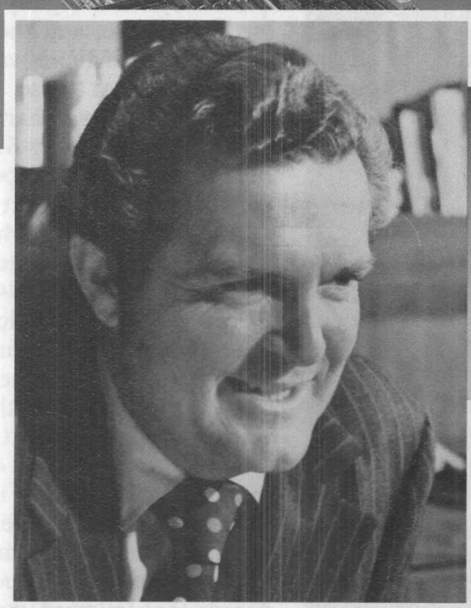
Another engineer who benefited from the universal need for more exact measurement was Joseph Keithley (see Chapter 4). In 1948 he had written an article for *Electronics* on the development of a low-frequency oscillator that employed the resistance-tuning technique of the HP 200. In 1951, he built his own model 200, and it, too, was a first for the industry: a dc electrometer voltmeter with an input impedance of 10^{14} ohms. In the late 1950s, the model 410 picoammeter, the 610 electrometer, and the 150 microvoltmeter were introduced, the beginning of Keithley's major product lines.

But the instrument most closely associated with engineering, not only throughout the 1950s but also the decade that followed, was the oscilloscope.

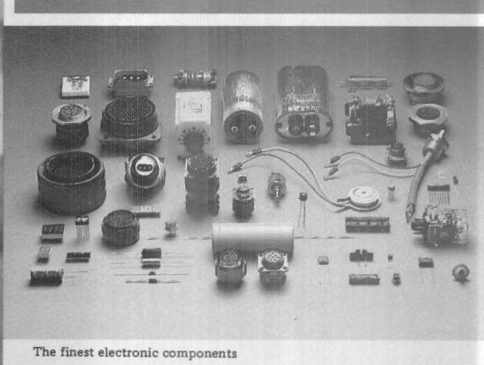
In the 1950s Tektronix committed itself to the manufacture of its own CRTs. At what proved to be a critical point, Howard Vollum suggested that a helical configuration of post-acceleration plates be tried. This design increased the brightness of the display and permitted the tube to work at higher writing speeds. Scopes moved from the 10-MHz to the 100-MHz region.

Hamilton/Avnet makes





Tony Hamilton, President



The finest electronic components

In 1957, Tony Hamilton, then Director of Purchasing for Lear, Inc., left that position and began a manufacturer's representative company. Within a year he took on the General Electric line of tantalum capacitors for distribution. This was the beginning of Hamilton Electro Sales. A year after going public in 1961, Hamilton merged with Avnet, Inc. and their chain of electronic distribution facilities. Under the leadership of Tony Hamilton, both chains grew with stocking locations in every major U.S. and Canadian market.

In 1970, Hamilton Electro Sales and Avnet Electronics merged, forming the present Hamilton/Avnet which has grown to 40 stocking locations serving over 110,000 buying points with gross sales in excess of $530,000,000.

PROM Programming History. Whatever your programming needs, be they bipolar, MOS, or FPLA, Hamilton/Avnet's local PROM programming centers are at your service. Customer PROM orders will be processed immediately because each location is backed by a system of the best programming equipment, in-depth inventory, and local programming specialists. The constantly upgraded equipment is able to meet the ever expanding PROM technology and can already handle 32K and 64K requirements.

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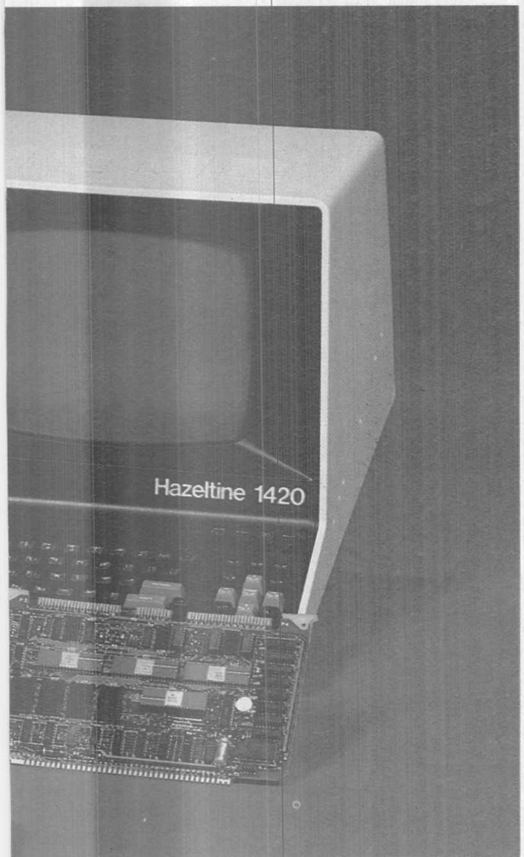

Hamilton/Avnet makes the military commitment

million dollar commitment on the military components front. In being a locally franchised distributor, we have been able to secure long term agreements from key military components manufacturers such as Advanced Micro, Fairchild, Harris, Intel, Motorola, National, RCA, and Signetics. While typical lead times are 25-50 weeks, we can usually deliver your product in less than 24 hours. Hamilton/Avnet's military product specialists know customer needs and assure our traceability and documentation system backs each product with a complete history. All of our mil-spec products are kept in a restricted warehouse area to insure their integrity.

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Computer Products History. We have over a $15,000,000 inventory of quality computer products such as Centronics printers, Hazeltine terminals, and Shugart floppy disk drives, plus microcomputers and their components including chips, logic devices, and EPROM's from Advanced Micro, Digital, Intel, Motorola, and National.

Computer Products Specialists at each location provide an index of knowledge and products for potential users, along with local demonstration centers where designers can evaluate equipment through hands-on demonstrations. Equipment support is provided by local literature centers where users can purchase the programming, technical and higher level programming language manuals to meet their requirements.

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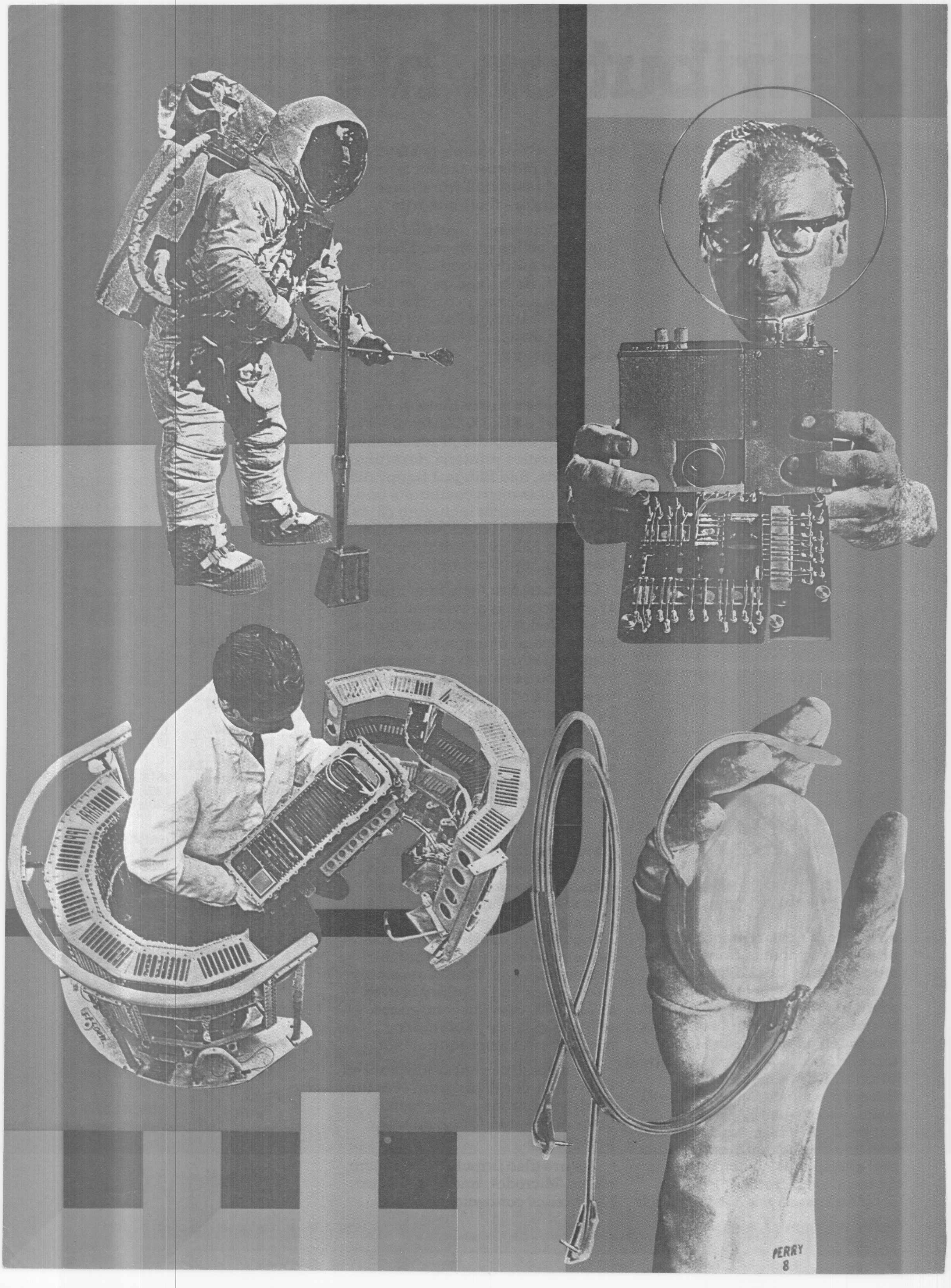
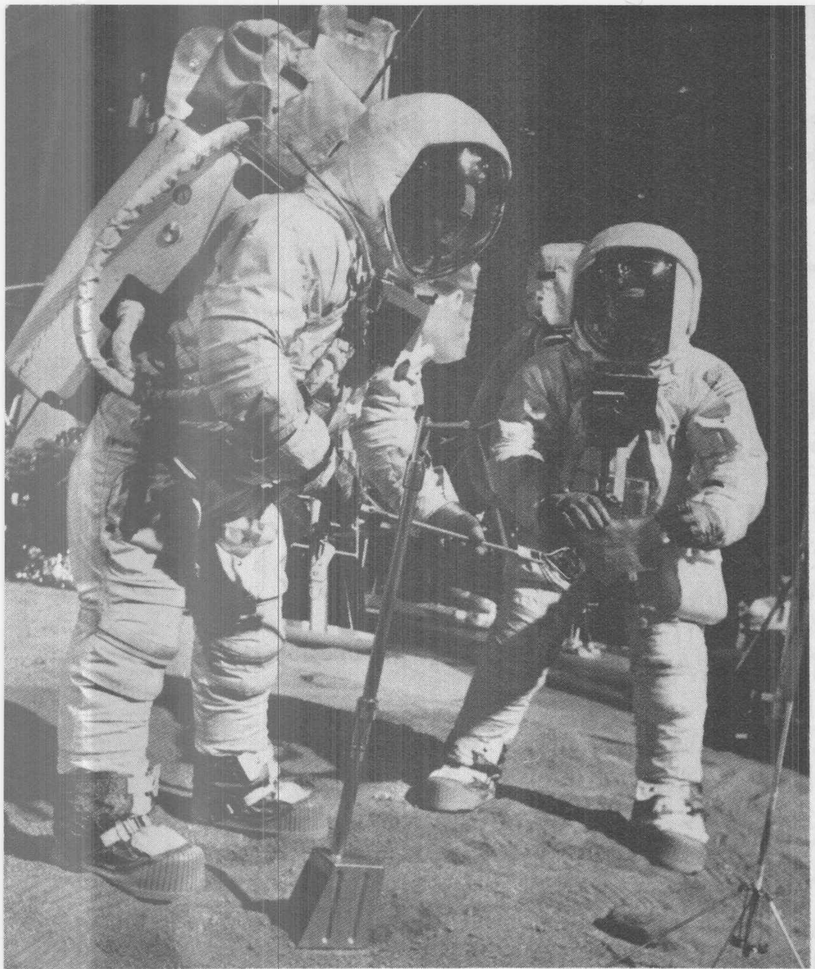

PERRY
8

COMPUTERS & SPACE

THE IDEALISM INSPIRED BY PRESIDENT JOHN F. KENNEDY WAS SOON DISPELLED BY HIS ASSASSINATION AND U.S. INVOLVEMENT IN THE VIETNAM WAR. BUT BY THEN THE SPACE RACE WAS WELL UNDER WAY. LEANING HEAVILY ON LARGE DIGITAL COMPUTERS FOR GUIDANCE AND CONTROL, APOLLO TOOK MEN TO THE MOON, AND WEATHER, COMMUNICATIONS, AND NAVIGATION SATELLITES WENT INTO ORBIT. IN EVERYDAY LIFE COMPUTERS ALSO CONSOLIDATED THEIR POSITION AS SEMICONDUCTOR DEVICES WERE PERFECTED AND THE MONOLITHIC INTEGRATED CIRCUIT WAS BORN. BY THE END OF THE DECADE, ELECTRONICS AND SOCIETY WERE ON THE BRINK OF THE DIGITAL REVOLUTION.

Chapter 7



Some saw it as a decade of idealism after 10 years of relative apathy. Others called it the violent sixties. To still others, it was the sensual sixties. It had freedom marches, the Peace Corps, and the dream of a political Camelot to right the wrongs of the past. There were racial conflicts, assassinations, and war in Vietnam. For some, it ushered in liberated sex, pornography, drugs, and flower children.

In his inaugural address in January 1961, President John F. Kennedy envisioned the opening of a "New Frontier," led by "a new generation of Americans." He called on Americans to "ask not what your country can do for you—ask what you can do for your country."

Within three months the bold, uplifting spirit was flagging. On April 12, 1961, the Soviet Union placed the first man in space, Yuri Gagarin. He orbited the earth once and returned to Russian soil.

On May 25, 1961, in a message to Congress "on urgent national needs," the President called for a greatly enlarged space program, including the landing of an American on the moon by 1970. Thereafter the U. S. gradually recouped its confidence, and it placed its own astronaut, John H. Glenn Jr., in orbit on Feb. 20, 1962. Glenn made three passes around the earth, and the nation was on its way to space supremacy.

Then Nov. 22, 1963: a routine Presidential visit to Dallas, Texas, with crowds cheering the Chief Executive as his motorcade passed. Suddenly a seeming fusilade of bullets poured forth. John Fitzgerald Kennedy, the youngest American to be elected President, was also the youngest to die in office.

Other important figures besides the President were assassinated in the decade. The Rev. Martin Luther King Jr., the black civil-rights leader, was slain by a rifleman in Memphis in April 1968. Sen. Robert Kennedy, the President's younger brother, was shot to death on June 5, 1968, in Los Angeles as he campaigned for the Democratic Presidential nomination.

The early sixties also marked the start of a drive by black people in the United State for equal rights. Some 250,000 blacks and whites marched in Washington in August 1963 in a show of strength. The frustration felt by blacks exploded in riots in some 60 cities between 1964 and 1967, killing 140 and injuring 4,550.

The middle sixties saw the war in Vietnam escalate sharply. American intervention had begun mildly in 1959 with the sending of military "advisers" to help the Republic of South Vietnam defeat Communist guerrilla forces supported by North Vietnam. The advisory role began to expand under Kennedy, grew to a "brush war," and, under President Lyndon B. Johnson, became a major conflict.

Through all the turmoil, the National Aeronautics and Space Administration kept its sights on landing a man on the moon. On Dec. 21, 1968, Apollo 8 became the first manned space vehicle to go into moon orbit. And on July 20, 1969, the crew of Apollo 11 radioed historic words: "The Eagle has landed." Man had set down on the moon. On that day at 10:56:20 p.m. eastern daylight time, millions of television viewers saw Neil A. Armstrong take man's first steps on the moon.

After the moon landing it soon became evident that

Moonbound. The U. S. astronauts certainly dressed the part (far left). Here, Apollo 11 lunar module pilot Edwin E. Aldrin (front) and spacecraft commander Neil Armstrong, the first man to walk on the moon, scoop material from a replica of the moon's surface.

Mission control. Backing up the spacecraft were dedicated people in the Mission Operations Control Room in NASA's Mission Control Center, Houston. The earth's image (at the front of the room) was telecast in late 1968 from the Apollo 8 176,000 miles away.

NASA really had nowhere to go for an encore. From an electronics industry viewpoint, the milestone occurred in the summer of 1966, when the space agency's budget peaked at an annual rate of about $6 billion. After that the budget began a long downward slide. A follow-on lunar exploration program and ambitious manned missions to Mars were abandoned in the social upheavals of Vietnam and the civil rights movement.

The $23.5 billion Apollo program lasted 11½ years and landed 12 men on the moon (one mission, Apollo 13, had to be called back without a landing after an oxygen tank ruptured). The missions gathered 840 pounds of moon rocks for scientific analysis and gave the American people one of their few reasons to rejoice in the turbulent decade. Overshadowed by Apollo were some significant achievements in unmanned space flight, notably the applications satellites for communications, meteorology, and earth-resources surveys.

The year 1960 had found the U. S. electronics industry scarcely pausing for breath as it completed a decade of unparalleled growth. Sales of electronic parts and systems had grown fourfold since 1950—to more than $10 billion yearly. Electronics was now a basic industry in the U. S. economy. Its growth, at a compound rate of nearly 15% yearly, was well above the growth rate of industrial production generally, and it was attracting the attention of Wall Street.

The integrated circuit was on the horizon. Patrick E. Haggerty, president of Texas Instruments, was talking about electronic systems no longer being "circuit-dominated." Rather, an understanding of materials—particularly semiconductor materials—was important, he said. A result of these new efforts was the IC, which was to transform electronics just as the transistor had done before it.

At first, application of ICs was limited to such programs as Army battlefield missiles, the antiballistic-missile effort, some secret cryptographic gear at the National Security Agency, the ill-fated X-20 Dyna-Soar military manned space program, and the Saint, Surveyor, and Syncom spacecraft.

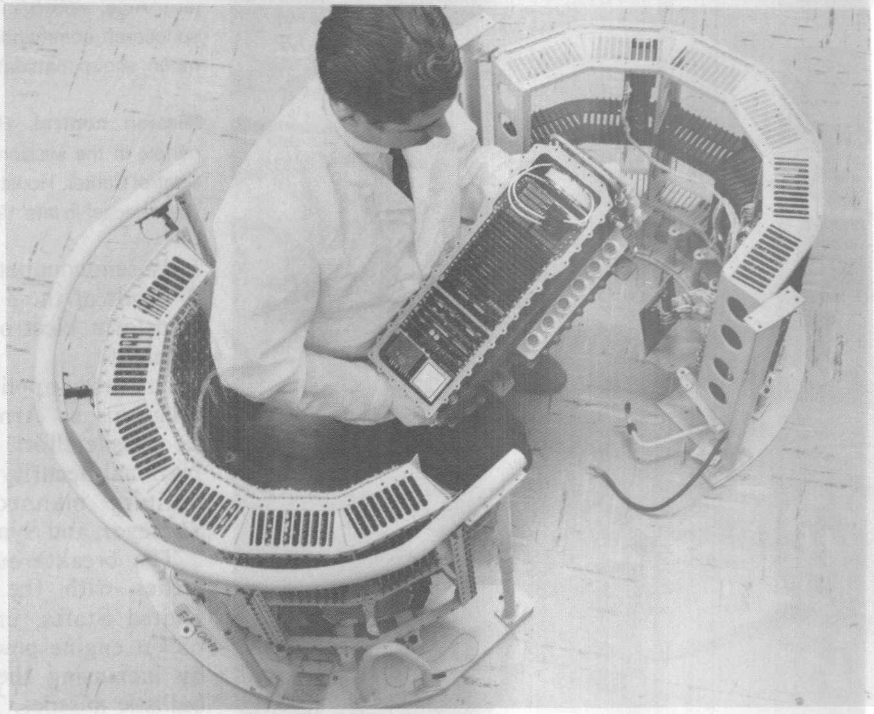
The breakthrough for the IC industry came in the sixties with the Minuteman missile program. The United States, unable to match the Soviet Union in rocket engine power, moved to achieve strategic parity by increasing the effectiveness of its intercontinental ballistic missiles. The decision was made to upgrade the improved Minuteman with weight-saving microcircuits.

The Minuteman improvement program demanded what was then the unprecedented production rate of 4,000 ICs a month. This requirement ultimately was instrumental in propelling Texas Instruments to world leadership in the manufacture of ICs, a position that it still holds in 1980.

If there was one outstanding technical trend toward the end of the decade, it was that integrated circuits were swarming into everything—large-scale computers and minicomputers, desktop calculators, cash registers, TV sets, radios, tape recorders, stereo components, numerical controllers, and telephone switching systems, to name only some products.

The two main professional organizations for electrical engineers—the 79-year-old American Institute of Electrical Engineers and the 51-year-old Institute of Radio Engineers—merged in January 1963. There had been much overlaping of interest in the two organizations and duplication of effort. The IRE, with 100,000 members at the end of 1962, had long since passed the AIEE in membership. The merged organization, the Institute of Electrical and Electronics Engineers, counted some 154,500 members in 1963. Despite slight declines in 1964 and 1967, membership rose until, by 1970, it reached 169,100.

Interest in radio astronomy also accelerated in the 1960s, and some notable radio telescopes were built. They included a dish with a 147-foot diameter constructed in 1962 at Green Bank, W. Va., for the National Science Foundation and a 328-ft dish put up at the same site in 1967 for the National Astronomy Laboratory. But overshadowing all was the dish completed in 1965 on 18.5 acres carved out of a valley at Arecibo, Puerto Rico. A combined radio telescope and radar facility that cost the Advance Research Projects Agency



Shrinking. Integrated circuits applied in the inertial guidance system of the Air Force's Minuteman ICBM set the pace for small size and reliability. The D37B computer developed by North American Aviation's Autonetics division in 1964 (being held at center) dwarfed Autonetics' older D17 unit.

$9 million, it had the world's largest antenna: a dish with a 1,000-ft diameter.

The Arecibo radio telescope was 16 times more sensitive than the one at Jodrell Bank, England, and it had 256 times more radar power. Its dish, using a spherical reflector of galvanized steel mesh, could pick up signals 10 to 12 billion light years away, double Jodrell Bank's listening range. It was 10,000 times more powerful than an installation at Milestone Hill, Mass., that had bounced a radar signal off Venus.

Since the formation of the earth, the infinite region called space had been unconquerable. Then the frontier fell virtually overnight. In 12 short years, starting in 1957, man broke the chains of earth's gravity, advanced to scientific and commercial exploitation of space, and also took his first steps on the moon. Few "impenetrable" barriers had collapsed so rapidly in the history of civilization.

The electronics industries led this push into the space age, moving quickly to extract the maximum practical benefit for earth dwellers. The decade of the 1960s saw the orbiting of communications satellites that accommodated radio, telephone, and television services; weather satellites that gave forecasters better information about storms and ice fields than they had ever had before; scientific satellites that yielded a cornucopia of information about the earth, the atmosphere and space; and navigation satellites that allowed pinpointing of positions on earth.

Communications was a fertile and obvious field for early cultivation. Echo I, launched Aug. 12, 1960, from Cape Canaveral (later renamed Cape Kennedy) in Florida, was the world's first passive communications satellite—that is, it reflected passively to receiving stations on earth radio waves that were beamed at it from transmitting stations on earth. The first active communications satellite, Courier 1B, was orbited by the U. S. on Oct. 10, 1960. Active satellites have radio receivers and transmitters on board. They receive radio waves from transmitting stations on earth, amplify the signals and retransmit them to receiving stations on earth.

Active satellite technology took a big step forward in 1962 with the American orbiting of Telstar I, the first satellite to relay television programs between the U.S. and Europe, and Relay I, which retransmitted radio, telephone and television signals. Telstar and Relay were true amplifiers in the sky. They retransmitted communications in real time, unlike some of their predecessors, which just recorded on tape and retransmitted. They also made extensive use of amplification, and this provided higher signal strength at the ground station, thereby simplifying the job of that expensive installation.

The Telstar satellites were designed by the Bell Telephone Laboratories and operated by the American Telephone and Telegraph Co., and they owed some of their origins to AT&T's work with the Echo satellite.

Following the launching of Telstar I by a Thor-Delta rocket, Telstar II—essentially the same satellite—was lofted in May 1963. Like its predecessor, it sent 2.25 watts of power to the receiving station by means of a traveling-wave tube. This microwave vacuum tube was to become a standard for bandwidth, power, and reliability throughout the decade, even while solid-state devices were making inroads into almost every other part of satellite communications equipment.

The Telstars furnished either 600 voice telephone or one television channel—each needed the same bandwidth. But the satellites were still basically experimental

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1-250 MHz	5.5	7.0
0.5-500 MHz	6.5	8.5

Isolation (dB)		Typ.	Max.
0.5-5 MHz	**LO-RF**	50	45
	LO-IF	45	35
5-250 MHz	**LO-RF**	45	30
	LO-IF	40	25
250-500 MHz	**LO-RF**	35	25
	LO-IF	30	20

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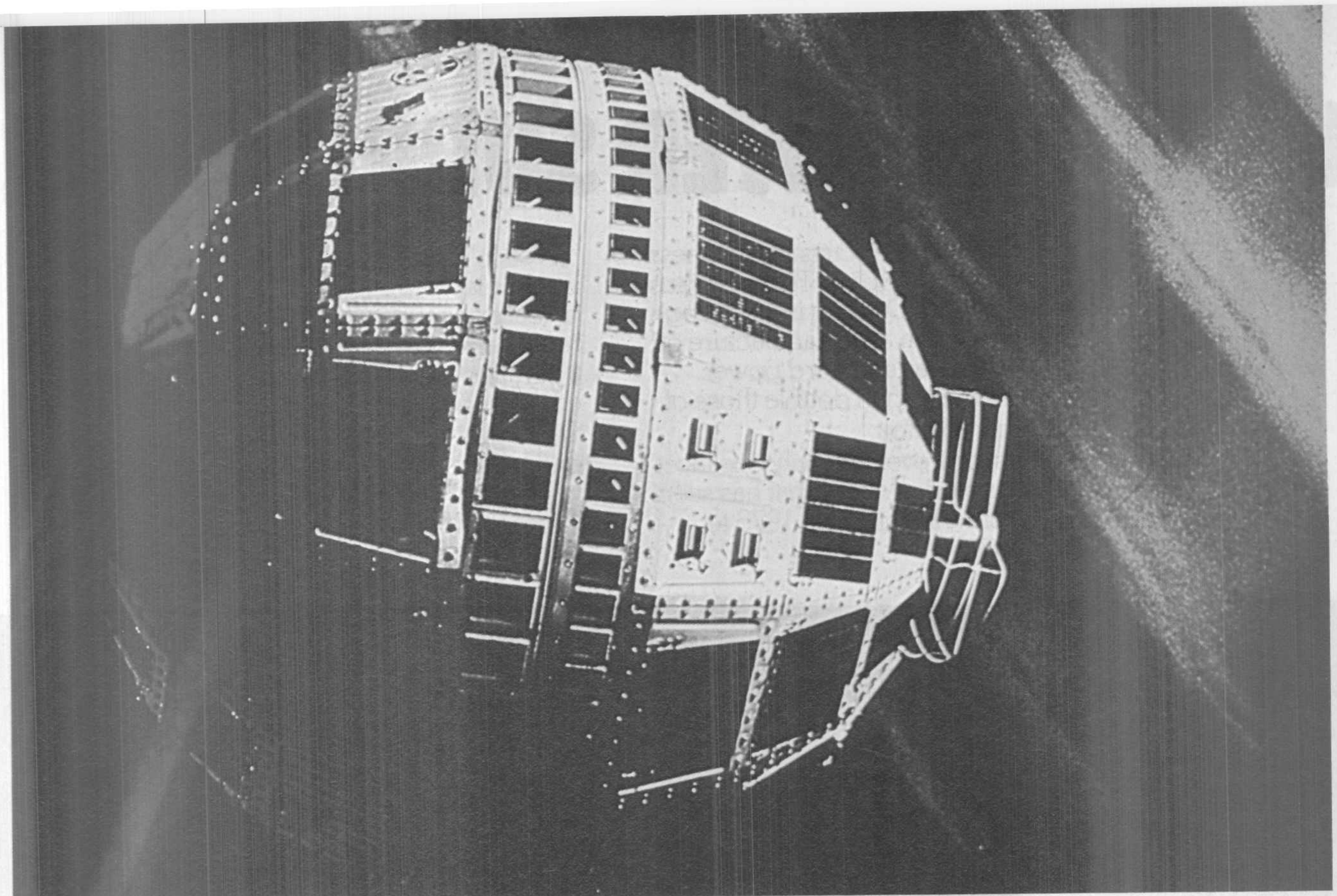


and not a full commercial success. Relay, a Radio Corp. of America undertaking, was also largely experimental.

The major questions faced by satellite makers, operators, and users in the early 1960s were the political, social, and economic issues of regulation and monopoly. Clearly a number of competing satellites run by separate companies would be as undesirable as a number of separate telephone companies would have been a hundred years earlier.

The U. S. Government considered this issue, and the Communications Satellite Act of 1962 led to the establishment in 1963 of the Communications Satellite Corp. in Washington, D. C. Comsat, as it came to be known, received responsibility for running domestic satellite communications. It became the domestic common carrier.

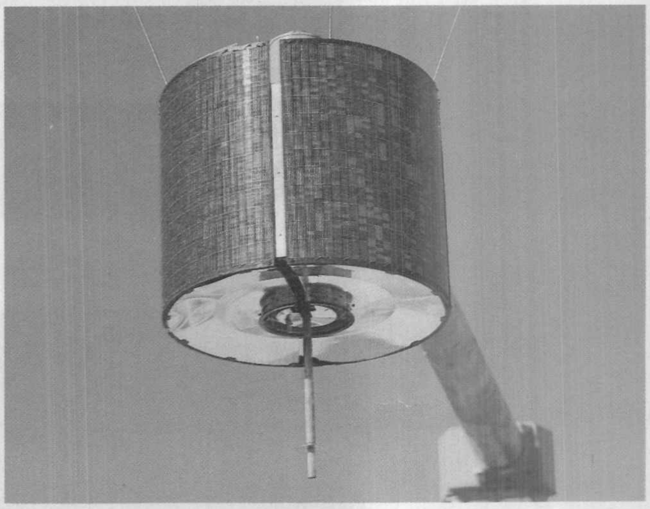
But what about international satellite traffic? Responding to this challenge, 11 countries set up the International Satellite Telecommunication consortium in August 1964, also in Washington, D. C. Intelsat was charged with designing, developing, constructing, maintaining, and operating the space segment of a satellite-based global commercial communications network. Like Comsat, Intelsat was to succeed commercially: by 1978, direct service had expanded to 124 countries.

The first commercially successful communications satellite was launched by Intelsat at Cape Kennedy in April 1965. Intelsat I—or Earlybird, as it was called—was planned as an 18-month operation. Instead it lasted nearly four years in synchronous orbit, until January 1969. Nothing in the satellite failed. Its place was taken in 1969 by the Intelsat II and Intelsat III series, which covered both the Atlantic and Pacific Oceans.

During this time the U. S. military was not idle; it, too, adopted communications satellite technology. The first military satellite, the DSCS-1, was launched in June 1966 from Vandenberg Air Force Base in California. Military satellites usually had confidential missions. These included not only communications but also reconnaissance of foreign territory by electronic and optical sensors. Orbits were synchronous or nonsynchronous, depending on the mission and the equipment packages.

Meanwhile, starting with Vanguard II in 1959, weath-

In space. The first communications satellite to relay TV signals between the U. S. and Europe was Telstar I, shown in this artist's rendering. The experimental Telstar I and Telstar II, launched in 1962 and 1963, were designed by Bell Laboratories for AT&T.



Farther out. Intelsat I, or Earlybird, was the first commercially successful communications satellite. Built by Hughes Aircraft for the International Satellite Telecommunications consortium, it operated for almost four years after a 1965 launch into a synchronous orbit.

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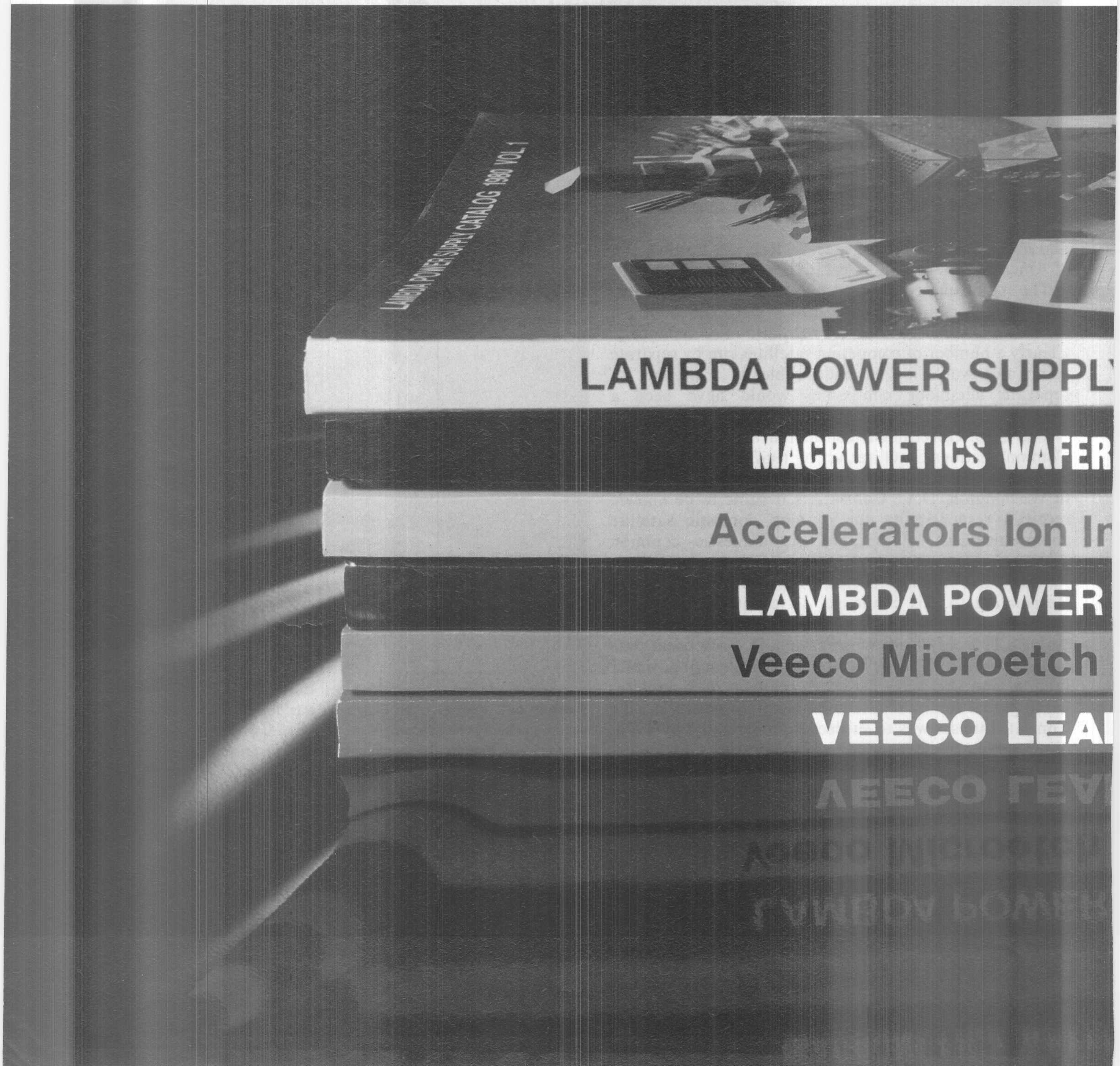

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er satellites began to give meteorologists reports that much improved long-range forecasting. A long line of Tiros satellites was launched by the U. S. in the 1960s—from Tiros I in April 1960, the first satellite to take detailed photos of weather, to Tiros VIII in December 1963, the first satellite to send photos of clouds automatically to earth. The Tiros series, from Radio Corporation of America, was followed by the Nimbus, and each succeeding launch brought new advances.

Not all of the satellite activity of the sixties was strictly American, though the U. S. dominated the field. In mid-1962, for example, the S-52, a joint project of Britain and the U. S., went into orbit. Built by Westinghouse Electric Corp., it was not designed for communications but for scientific research. Measurements were made of galactic noise, high-altitude atmospheric ozone, and the size and number of micrometeorites in the atmosphere.

The U. S. also cooperated with the West German Post Office, which has responsibility for communications in that nation. The Germans tried out a transportable earth station supplied by ITT Federal Laboratories and installed by Standard Electric Lorenz, an ITT affiliate. The station operated at both the Telstar and Relay frequencies. It was used for West Germany's first direct satellite communication with the U. S.

From the outset, the U. S. placed a high value on the use of satellites for scientific research. The very first satellite it launched, Explorer I on Jan. 31, 1958, discovered the Van Allen radiation belt in space, and subsequent Explorer missions mapped this belt, exploring the region of space between 180 to 47,800 miles from earth.

In March 1962 the U. S. put up the first orbiting solar observatory, OSO-1. Then in September 1964, it lofted the first orbiting geophysical observatory, OGO-1. In February 1965 it began to measure meteorite density in space with Pegasus 1, and in April of that year Snap 1OA carried the first nuclear-powered rocket motor successfully into space.

To foster more precise navigation, a series of Transit satellites was orbited, starting in April 1960.

By 1964 the number of objects in earth orbit had reached 400 or so, and the U. S. had a Space Track radar, with a phased-array antenna as high as a 15-story building, to keep track of all the flying objects. The $30 million Bendix radar, the AN/FPS-85, was at Eglin Air Force Base in Florida. It fed its information into a Space Detection and Tracking System located in Colorado Springs, Colo.

Radar evolution was spurred in the 1960s by greatly increased use of the transistor and some complex integrated circuits. On top of this, new families of microwave components were developed that gave the radio-frequency front end of radar sets hitherto undreamed-of capabilities.

Typical of these devices were low-noise parametric amplifiers, transistors in the microwave frequency range up to about 5,000 megahertz, and various Gunn- and avalanche-effect diodes used for oscillators. Before these solid-state devices were available, radar designers had been prevented from pursuing sophisticated designs by the unreliability of the complex circuits they needed.

A great part of the effort in radar development went into signal processing. Improvements were made in radar resolution—particularly range, the determination of whether or not targets were moving, and background clutter rejection—and in various forms of electronic, rather than mechanical, beam scanning.

These scanning systems worked by distributing many radiators over the scanning aperture and varying the phase of the signal transmitted from each radiator with respect to its neighbors. Inexpensive, readily phase-shifted radiators—perhaps 1,000 in one antenna—as well as simple digital controls were required to make such a system work. Cost was a major problem with these phased arrays, and in spite of the availability of solid-state components, they did not meet wide acceptance in the 1960s.

Many practical mobile radars were developed. Typical was a mortar-locating radar that in its original version weighed 7 tons with an associated power generator. A new semiconductor version weighed 1 ton and had improved performance.

Of course, the most obvious use of the new semiconductor technology was in hand-held radars, which became feasible for the first time. These systems usually generated only about 5 to 500 milliwatts, which, while low-level, was sufficient for a diversity of applications.

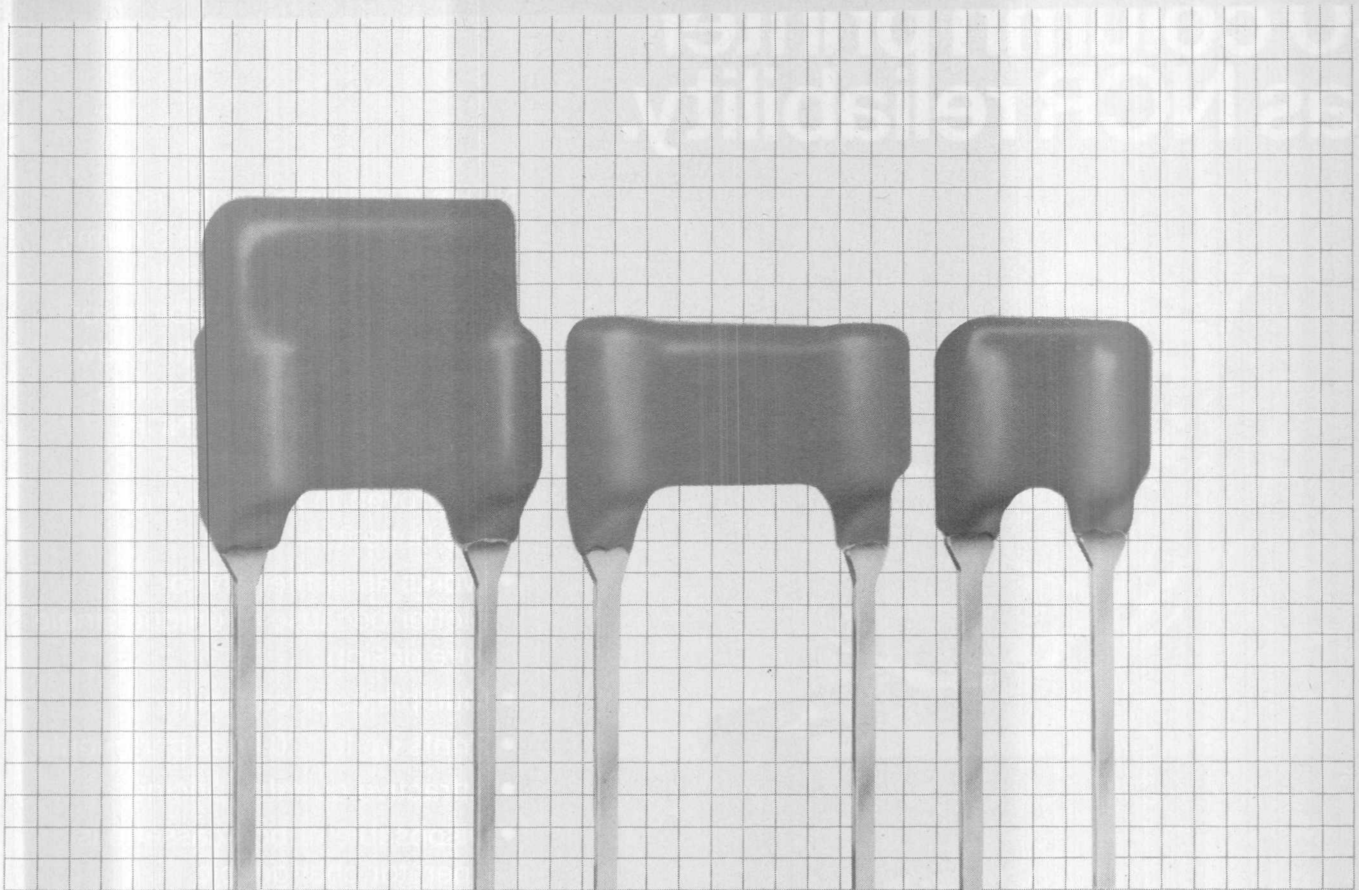
In civilian aviation, the 1960s brought planning for an American dream—a supersonic transport that would top the Anglo-French Concorde, which was the first SST on the drawing boards. But the dream turned soon enough into a nightmare of controversy over high costs, not only of development but also in feared damage to the environment.

Boeing, the prime contractor on the American SST, was prevented from building a prototype; the National Aeronautics and Space Administration terminated work after more than four years of Federal funding. However, there was one major benefit from the program: the impact it had on advanced avionics development.

The SST project is credited with spurring the adoption of inertial navigation by the airline industry. The first such systems for jetliners were supplied by Sperry, but the market later was dominated by General Motors' Delco division and Litton. Delco had gained experience with the guidance system it had built for the Apollo satellite program.

The SST project also anticipated the trend to microprocessors and distributed computing. Boeing designed its supersonic aircraft with more than 20 computers embedded in instrument systems. The rationale was simple: the company feared a breakdown of even a redundant central-computer system would create unacceptable risk for a commercial SST.

In other avionics developments not directly related to the SST project, distance-measuring equipment (DME) was introduced on new jetliners in 1961, and the Federal Aviation Agency (later renamed the Federal Aviation Administration) began using DME traffic control proce-



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dures for the first time on a nationwide basis. Also in 1961, the first doppler voice-over-radio (VOR) system was commissioned at Marquette, Mich.

In 1964 automated terminal radar and computer data processing were introduced for evaluation. Field tests led to a decision to replace the existing manual system with the automated terminal radar system. The conversion began in 1966 at Jacksonville, Fla., and continued over the next decade.

In the telecommunications industry, the emphasis was on solid-state electronics. The first effect was felt in 1964 in the New Jersey town of Succasunna (pop. 5,000). The Bell System office there became a pacesetter of the new order that promised to abolish manual and electromechanical switching in all Bell central offices by the year 2000.

According to a Bell spokesman at the time, the system at Succasunna was destined to "open the era of electronic switching, in which high-speed computers run systems that can perform more services faster, more reliably and with greater flexibility than only a few years ago."

The new system, called the ESS-1 (for No. 1 Electronic Switching System), had a stored memory that contained program-switching logic and a temporary memory that stored the transient information needed to process a call. The transient information included the digits being dialed and whether or not a line was busy.

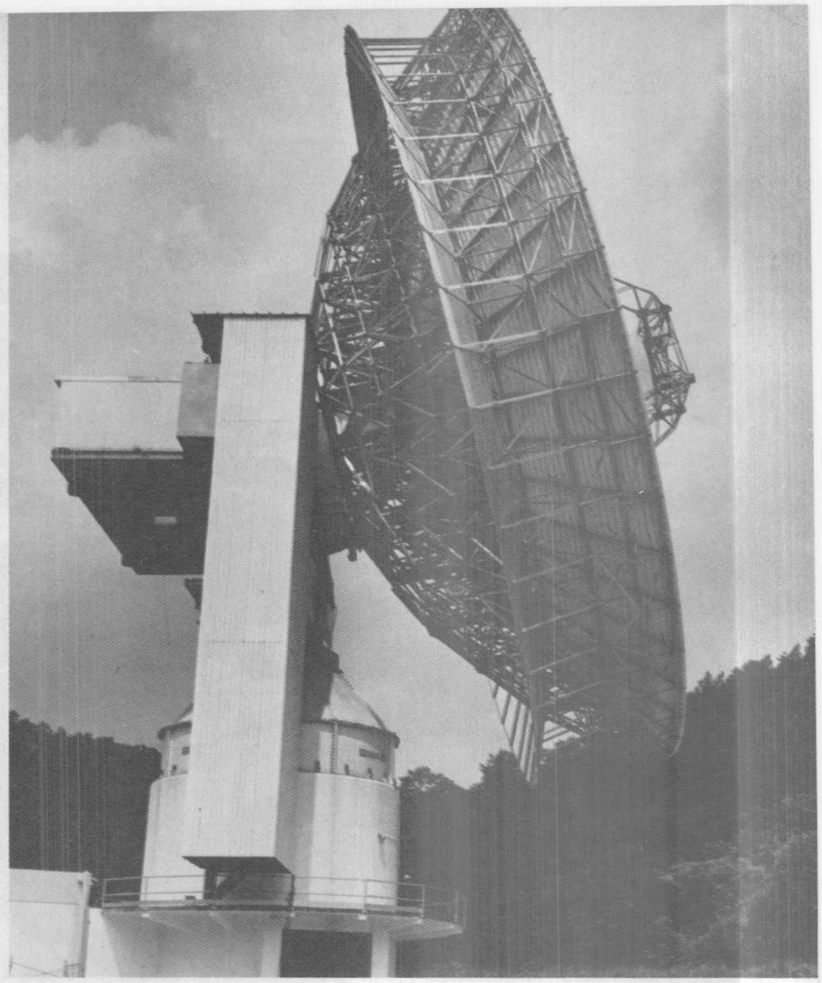
For the telephone company, the ESS-1 meant that the routine chores, such as maintenance and accounting, could be done at less cost. For the customer, the new switching system led to more services, such as conference calls and faster response to the placement of a call.

Adding to the importance of the ESS-1 was the fact that, although it was not totally digital itself (encapsulated dry-reed switches made the actual voice connections under electronic control), it was the forerunner of a family of digital switches that appeared in the U. S. in the 1970s.

In Britain, after some attempts at building an all-electronic switching system in the sixties, the British Post Office, in conjunction with Plessey Communications, designed the TX-E2 system. It used reed relays as the voice switching points, and it was put into service in 1966. Unlike the ESS-1, which could easily serve 10,000 lines, the TX-E2 was set up for either 4,000 or 7,000 lines. More than 1,000 such systems had been installed by the British by April, 1979.

Concurrent with electronic switching in the 1960s was the development of other digitally based telephone equipment built around the transistor and the integrated circuit. Typical of this equipment was the private branch exchange (PBX), which was totally electronic. Also introduced was the so-called repertory dialer, which enabled customers to store numbers in the handset.

And the demand for data services over telephone lines grew in the 1960s to such an extent that the U. S., Britain, and other countries soon developed data modems. The purpose of these mostly transistorized devices was to convert digital data into a form suitable for transmission over the analog phone line.



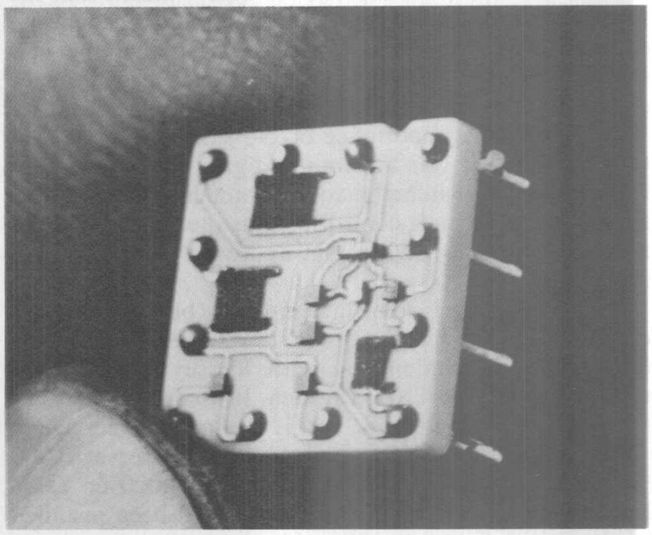
Towering. Earth stations, set up in the late sixties to communicate with the new satellites, were big. This one in Morgantown, W. Va., built by Philco-Ford's WDL division for Comsat Corp.'s Intelsat, has a 97-ft-diameter antenna, is 11 stories high, and weighs 470 tons.

Computers meanwhile raced feverishly to greater sophistication and wider use. The pace was such that computer makers were constantly revising their strategies. "Researchers postulate a possible future in which computational power will be available in a wall socket, like electrical power, or where every man who wants one can buy a small computer," wrote Douglas C. Engelbart, a senior research engineer at the Stanford Research Institute, in the April 28, 1961, issue of *Electronics*. "Perhaps the computer builder of 1961 finds it hard to comprehend the development of individually available computer power."

As the decade opened, the last of the first-generation vacuum-tube computers were giving way to the transistorized second generation. By 1964, a third generation was already on its way as the revolutionary integrated circuits began replacing discrete transistors. By the end of the decade, a newer, more compact computer—the minicomputer—was gaining popularity.

In 1960 the value of installed computer equipment was estimated at $1 billion, up from only $227 million in 1955. By 1965 that total reached $6 billion. As the decade closed, almost $8.5 billion worth of computers and peripheral equipment were shipped in 1970 alone.

The biggest customer became the U. S. Government. From almost a standing start in 1956, when only 90 computers served the Government, the number grew in 10 years to 7,575—more than 30% of the entire



Trend-setter. IBM shook up the computer world in 1964 with its new family of compatible computers, the System/360 (the model 30 is above), that made its earlier machines obsolete. IBM opted for hybrid modules (right), rather than still-developing monolithic ICs.

country's installed base. The Federal government's computer budget was about $50 million in 1959; by 1966 it was $115 million.

During all of the sixties computer software became ever more sophisticated. There was rapid growth of operating systems that supported a number of innovative features, such as virtual memory and timesharing. Standard programming languages emerged and were accepted by users for their applications.

The recognition that software was an expensive requisite of computer ownership was the death knell for a hodgepodge of incompatible computers on the market. In their places came so-called families of computers, all the members of which used the same architectural features—the same instruction set, addressing schemes, and the like. Hence all understood the same programs.

The space program was a major force in glamorizing the use of computers during the 1960s. Most of the computers used by NASA projects were, in fact, ground-based, general-purpose commercial units. In 1961, for instance, Burroughs ground computers guided the Atlas space missions. NASA used IBM computers to lead Astronaut L. Gordon Cooper on his 22 orbits of the earth in 1963. Burroughs computers guided the Ranger VI and VII unmanned probes to the moon in 1964, as well as Mariner IV to Mars. And IBM's Federal Systems division helped NASA in the Apollo program.

With good economic conditions and Wall Street's infatuation with high technology, dozens of companies formed or diversified to enter the computer business. Among these were Memorex, Data General, California Computer, Ampex, Storage Technology, Pertec, Data 100, Sycor, and Xerox. Some companies carved market niches for themselves in areas like IBM-compatible peripherals and data-entry devices. Others created entirely new markets, with the minicomputer the best example here. At the same time the strenuous pace of change took its toll. General Electric and RCA were among the dropouts.

At the dawn of the decade, IBM, with its famous "think" slogan, dominated the computer industry the

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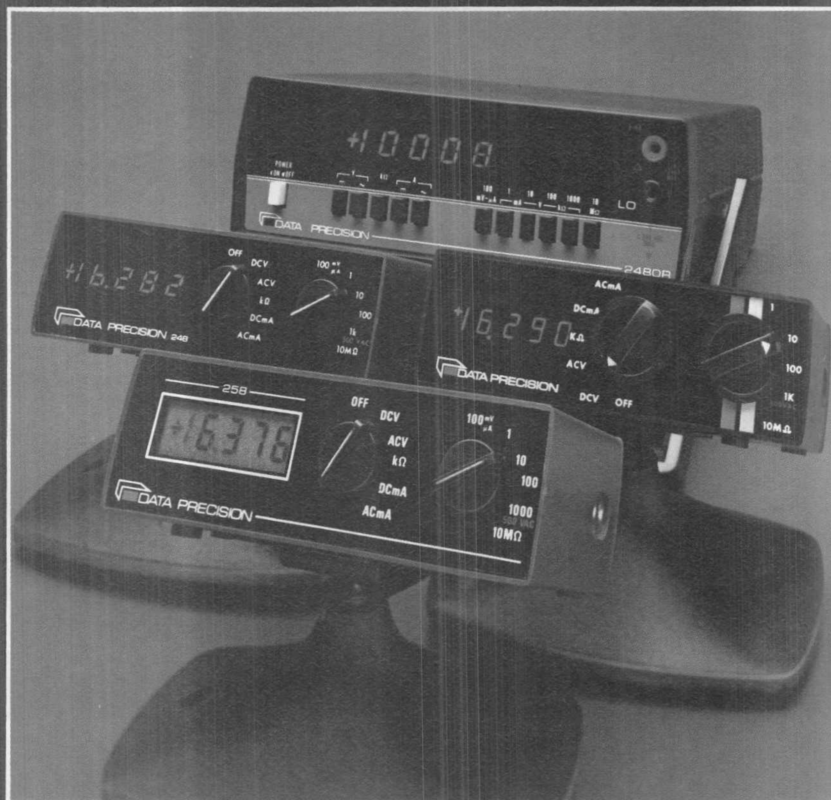

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At the top. Planned as the most powerful computer of its day, the top of IBM's line, the model 7330 data-processing system also referred to as Stretch, never did live up to its promise after it was delivered in 1961 to the Los Alamos Scientific Laboratory in New Mexico.

way it previously had the punched-card machine market. The marketing prowess of Thomas J. Watson had by then helped IBM gain an estimated 75% of the general-purpose computer market, and it maintained that share throughout the decade.

The IBM product line in 1960 was diverse. At the top was the Stretch machine, planned as the most powerful computer of its day. But when it was delivered to the Los Alamos Scientific Laboratory in New Mexico in 1961, the performance was below the promise of 100 times the performance of the model 709. IBM tried to salvage the machine by lowering the price, but the Stretch was pulled off the market shortly thereafter.

Although a marketing failure, Stretch had several innovative technical features, the most important of which was its instruction "look-ahead," or pipelining. This led to improved performance in other IBM models.

IBM had other, more successful products. The popular model 1401, introduced in 1959, rapidly became a workhorse of its day. It was joined in 1962 by the model 1441 and in 1963 by the 1460, the latter being twice as fast as the 1401. The transistorized 7090 computer line was expanded to include the top-of-the-line and lower-priced 7010 and 7044.

But during this time IBM management began to examine its prospects for the future and did not like what it saw. The low-end 1401 product line, manufactured by its General Products division in Endicott, N. Y., and the high-powered 7000 series from the Data Systems division in Poughkeepsie, N. Y., were beginning to overlap and to foster severe competition between the two groups.

An internal IBM study of the situation outlined in December 1961 the need for a single, compatible family of computers encompassing the full performance range between the 1401 and 7090. It recommended that the machines be truly general-purpose, having both business and scientific applications and equipped with standard interfaces to peripheral devices. Rather than just replace the 1401 or 7090 computers, the committee suggested that the new machines open new fields of computer applications. Management approved the plan.

The new effort used two of IBM's top computer designers, Gene Amdahl and Gerrit Blaauw, and one of the first decisions made affected the logic circuitry. Researchers reasoned that monolithic integrated circuits would not be available in volume in time to build the new computers. They recommended the use of hybrid ICs, with separate transistors and diodes soldered on a substrate. And, rather than reveal its designs and specifications to outside component suppliers, IBM decided to build the components itself. IBM opened its Components division in East Fishkill, N. Y., in 1963. The plant cost about $100 million to build.

On April 7, 1964, in its 50th anniversary year, IBM announced six computer models of its new System/360 line. Thomas Watson Jr., who had taken over as chairman from his father in 1956, called it the "most important product announcement in company history."

Writing in the April 20, 1964, issue of *Electronics*, editor Lewis H. Young reported: "With a single new

system, IBM had made every one of its commercial computers obsolete." The System/360 line and its hybrid Solid Logic ushered in the third computer generation.

In addition to the six computers—the models 30, 40, 50, 60, 62, and 70—the company unveiled 19 new memories and 26 input/output devices. The System/360 was also one of the first commercial computer lines to use microprogramming. In this way the various models, with their slightly different hardware, were all made to operate with the same instruction set.

IBM is estimated to have shipped some 33,000 computers during the six-year life of the line. But it required an enormous effort. Whereas Eniac had been developed for about $600,000, IBM spent over half a billion dollars on research and development for the 360. Between the time the program began and deliveries were in full swing in 1966, the company expanded its work force by more than 60,000 people to 190,000. Capital invested totaled $4.5 billion. In comparison, the Manhattan Project, which produced the atomic bomb of World War II, is estimated to have cost just over $2 billion.

But the hardware problems IBM had in building the System/360 were easy compared with the snags it encountered in developing operating system software.. The goal was a single operating system for all members of the System/360 family. An operating system gives a computer a "personality"; it administers the supervisory, or housekeeping, chores and thus makes it easier for the user to program the computer.

By the middle of 1965, however, it was apparent that the software development for the System/360's operating system was behind schedule. The first thing the company did was eliminate some of the more elaborate functions. Thirty-one features were "decommitted," as IBM put it.

In the end IBM was forced to deliver two operating systems: the Disk Operating System (DOS) for small-to-medium-sized machines and the more elaborate Operating System/360 (OS/360) for large machines.

Eventually IBM overcame many of the problems with the System/360 line and introduced more than 20 models. But in 1970 the family was replaced by the System/370, built entirely from monolithic integrated circuits. Portending the end of core memories, the model 145 of the System/370 was the first commercial computer to use solely monolithic ICs in its main memory. The new computer also incorporated a cache memory and error-correcting circuitry for the main memory.

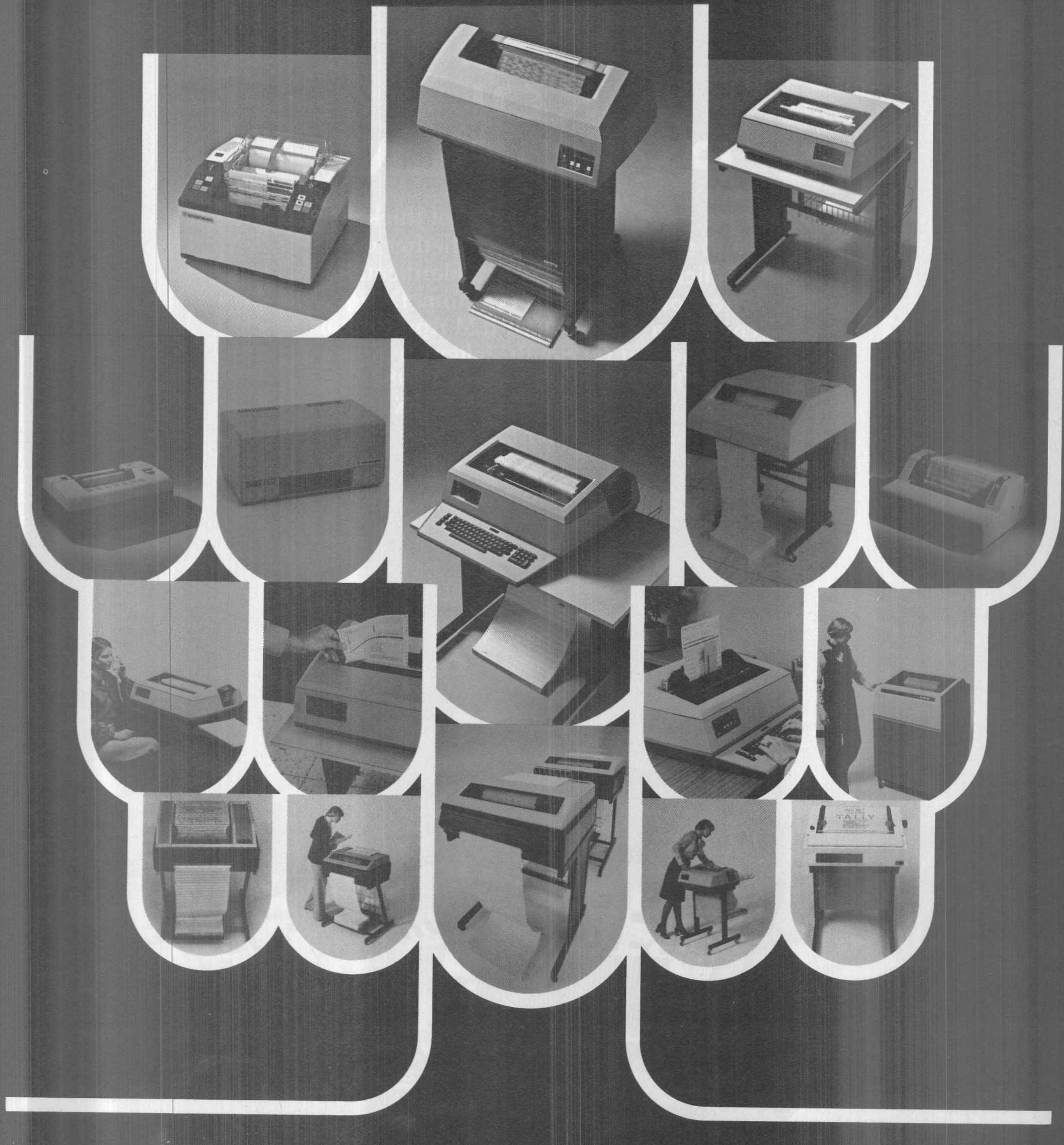
Despite their smaller size, IBM's major competitors—Burroughs, Control Data, General Electric, Honeywell, National Cash Register, RCA, and Univac—were in many cases more technically innovative than IBM. Sometimes they found that their ideas lacked credibility among potential buyers, however. Often it was not until IBM added a technical feature to its product line that the concept was accepted in the marketplace.

Like IBM in 1960, Sperry Rand Corp.'s Univac division in Blue Bell, Pa., had just finished a supercomputer effort, the Larc, built for the Lawrence Livermore Laboratories in California. Where IBM's Stretch had endeavored to employ the most advanced techniques and components available, Univac was more conservative: it built the Larc with readily available components. But the Larc, too, was not the commercial success its manufacturer had envisioned.

Univac was also having trouble in the market because its sophisticated Univac III, introduced in the early sixties, was not price-competitive with other medium-scale machines. In 1962 the company introduced its model 1107. Using a 128-word magnetic thin-film memory for control storage, in addition to traditional magnetic cores, the 1107 offered one of the fastest memory-access times available: three orders of magni-

Tubeless. All-solid-state computers were being brought to market in the early sixties by several companies. Control Data's desk-sized model 160-A was designed by Seymour Cray and delivered in 1961. It was one of the supercomputer maker's smallest machines.

On campus. GE began research in timesharing, a new way for many users to use a single large computer, at Dartmouth College in the early sixties. A key design element was a paging scheme for swapping data between main and peripheral memory.



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tude better than the microsecond access with cores. But even with nanosecond access, the 1107 was introduced too late to become competitive.

Univac introduced a third-generation version, the 1108, in July 1964. Since IBM had announced no successor to its large-scale 7090 computers, Univac was able to parlay the 1108 to dominance in the large-scale scientific computer market in the late 1960s.

With the 1107, Univac was on the leading edge of research into what promised to be a better way to build a memory: the thin-film technique. By 1966 the company was plating magnetic films onto wires, a method that was less expensive than making the planar thin films then in use. Univac incorporated the plated-wire memories into its models 9200 and 9300, unveiled in June 1966. The 9200 had a maximum memory capacity of 16 kilobytes, with a cycle time of 1.2 ns, while the 9300 could hold up to twice as much memory with a cycle time of 0.6 ns. Plated wire was eventually replaced by semiconductor memory, however.

Burroughs meanwhile was moving slowly into computers from a well-established position as a supplier of electromechanical business machines. The Detroit company introduced its most dramatic machine in 1961, the large-scale B5000 solid-state computer. The unit used an operating system that provided multiprogramming—one of the first with this capability—and it had an early form of what later became known as virtual memory.

Virtual memory, which did not become popular until IBM introduced it in 1972, was important because it overcame a fundamental obstacle to more powerful computing: restricted main memory. All data and programs must be in main memory for the computer to operate on them. Yet the operating systems, as they became more sophisticated, also became larger, occupying more of that precious memory resource and leaving less for users' applications programs. And because main memory cost so much, it was impractical to add more. The solution was to store the data not immediately being used on slower, less expensive peripheral storage drums and disks and to move the information into main memory only as needed. This obviously made the computer's memory seem larger than it physically was; hence the name "virtual."

When the Burroughs B5000, with its virtual memory, was delivered in 1963, however, it was disappointingly slow. The next year the company introduced the B5500, and this machine offered three times the throughput of the B5000 and a new multiprocessing capability. It became the basis for the so-called 500 family, which was expanded in March 1966 to include the third-generation medium-scale B2500 and B3500 computers featuring monolithic integrated circuits.

At the same time Burroughs introduced the large-scale 6500 computer, which featured a sophisticated operating system called the Master Control Program. It supported multiprogramming, parallel processing, real-time, and timesharing operations.

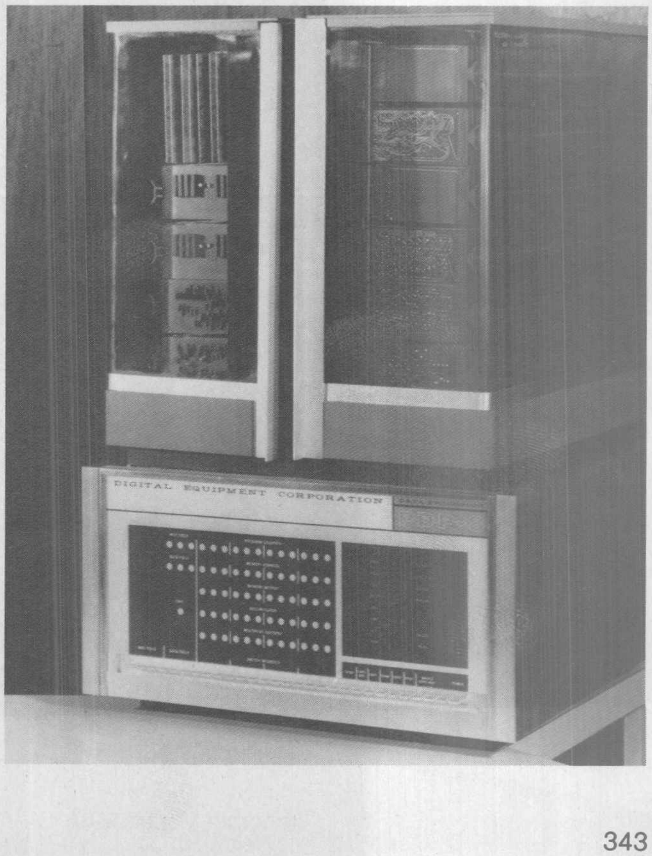
In 1967 Burroughs got an opportunity to try its hand at the type of supercomputer development attempted earlier by IBM and Univac. Daniel L. Slotnick of the University of Illinois had proposed a new computer architecture—a machine in which multiple streams of data could be operated upon in parallel by a single set of instructions. The Advanced Research Projects Agency of the U. S. Department of Defense funded the development of the computer, named Illiac IV.

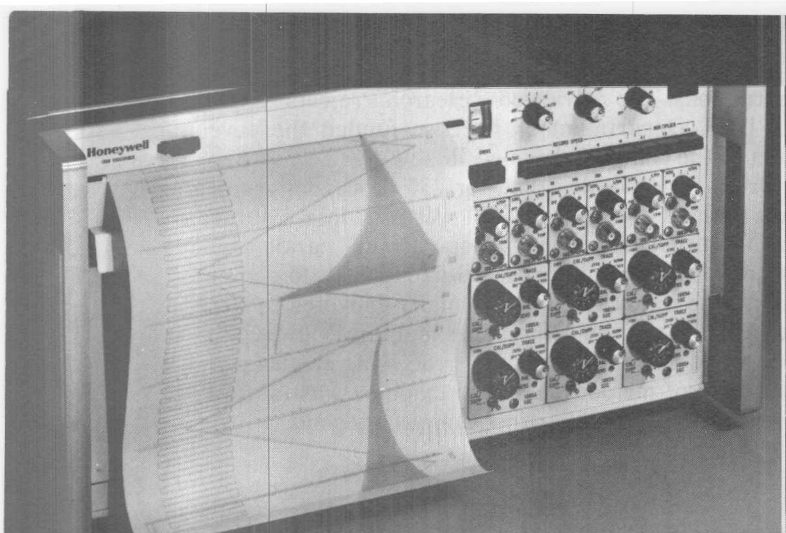
Original proposals called for 256 processing elements, each with its own 2,048 64-bit words of thin-film memory. The elements were to operate in parallel under control of a general-purpose Burroughs 6500 computer. But by the time Illiac IV was finally delivered in 1972 to the Ames Research Center in Mountain View, Calif., it was scaled down to 64 parallel processing elements and 1 megabyte of memory. Still the machine was impressive: it performed 200 million instructions a second.

The vicissitudes of supercomputer design in the 1960s did not keep one company from making a commercial success of its effort. In 1963 Control Data Corp. of Minneapolis announced the model 6600. Designed with multiple arithmetic and logic units coupled with 10 peripheral processors, the machine could perform more than 3 million operations a second. This was more than three times the speed of IBM Corp.'s ill-fated Stretch.

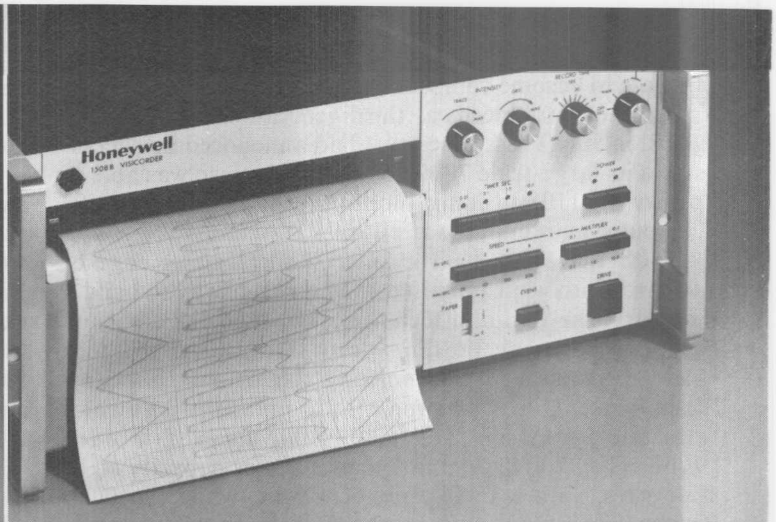
IBM attempted to counter with the models 90 and 95 of the System/360, but after significant development problems, these were withdrawn from the market in 1967. In their place IBM unveiled the model 85 of the System/360 in 1968. It incorporated cache memory (the

Progenitor. Digital Equipment Corp. is credited with creating the minicomputer when it introduced its 12-bit Programmed Data Processor, model 8, or PDP-8, in 1965. It had a 4,096-word memory and was the first computer to sell for under $20,000.

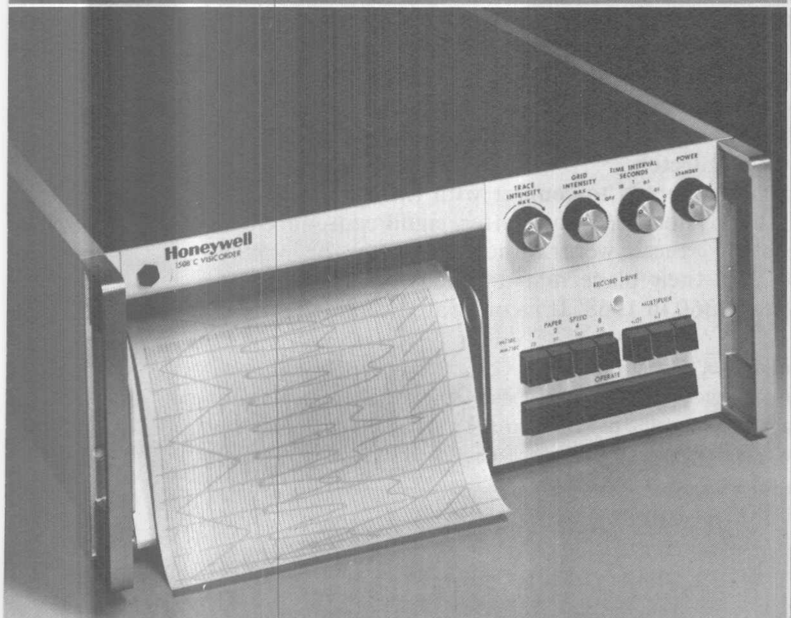




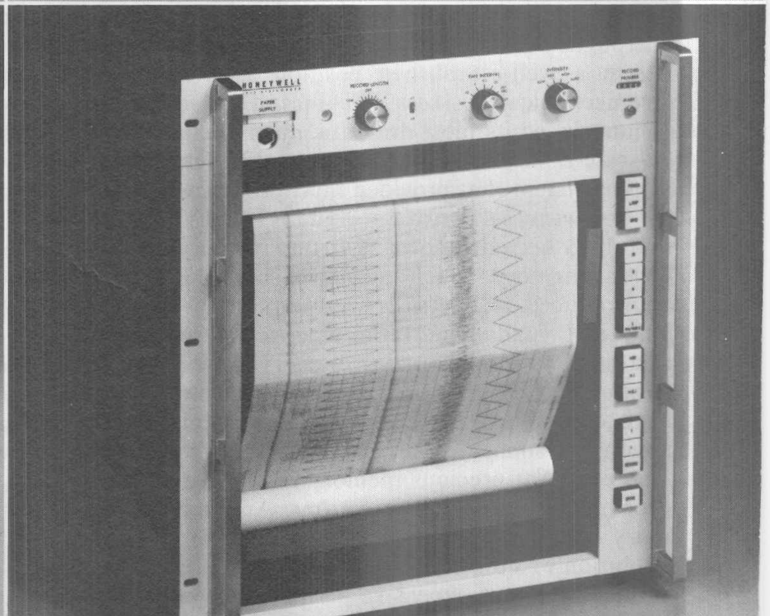
Visicorder Model 1858



Visicorder Model 1508B

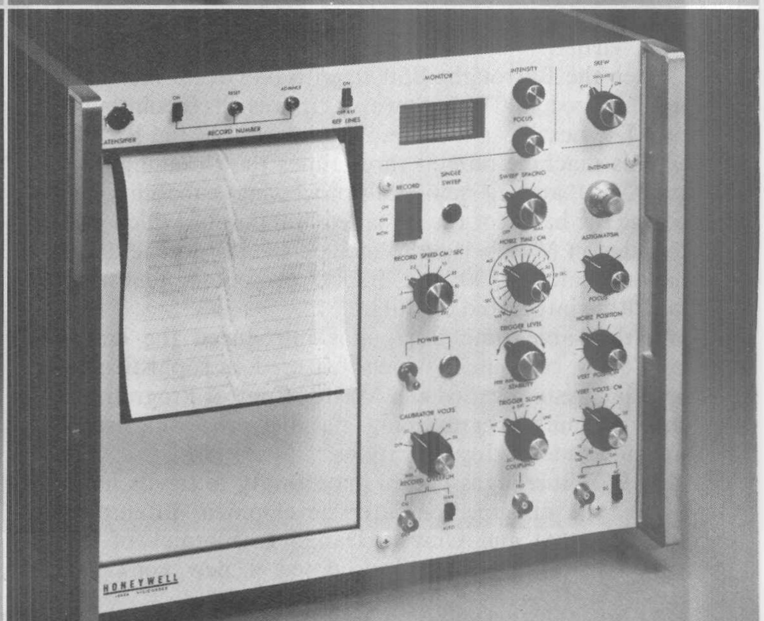


Visicorder Model 1508C

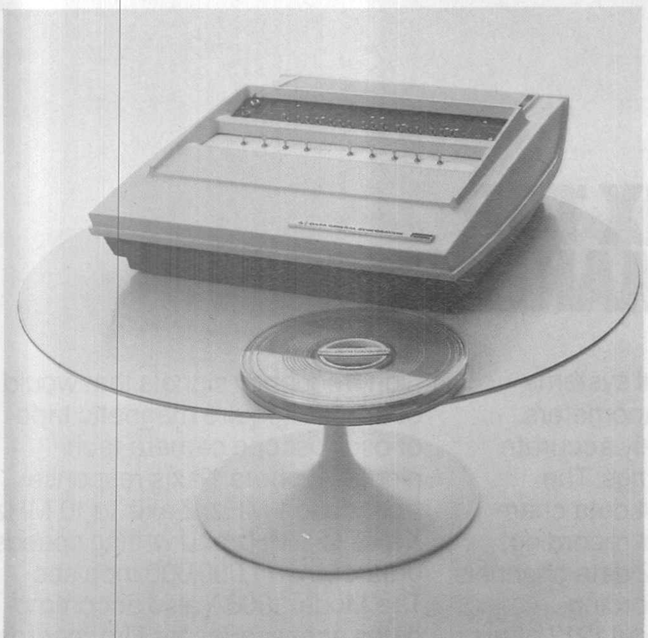


Visicorder Model 1912

Visicorder Model 1856A



Visicorder Model 1806A



Powerful. The Nova entered the minicomputer sweepstakes in 1968, introduced by Data General, a company founded that same year by three ex-DEC employees. Nova's price was low—$8,000—and it offered mixed and matched RAM and ROM to 32,000 words.

first time this was used in an IBM machine) to improve its speed of memory access.

That same year Control Data announced its large-scale 7600, which executed between 20 million and 25 million instructions a second. IBM followed with its System/360 model 195 in 1969, the first IBM machine to use monolithic integrated circuits, but the machine was never as popular as the Control Data units.

Among the most quiet—and successful—computer makers in the 1960s was the National Cash Register Co., Dayton, Ohio. It stuck with its 300 series, introduced in 1958, until it joined the third computer generation in 1968 with its Century Series, based entirely on monolithic integrated circuits. The new machines used a second generation of thin-film memory.

By now timesharing services had become one of the hottest developments in the industry, and it had all started in the early 1960s with research at Dartmouth College in Hanover, N. H., by General Electric, then headquartered in New York. In the timesharing mode, many users can share a computer by dividing not its hardware but rather its operating time. In this way the large and relatively expensive computers of the day, kept in special environmentally controlled rooms, could be used via phone lines by many people at once.

General Electric started one of the first commercial timesharing services in 1965. The following year IBM opened its Service Bureau company, which initially linked 125 System/360 computers at over 80 offices, and Control Data opened its Cybernet service. By 1968 dozens of companies were offering remote computing services.

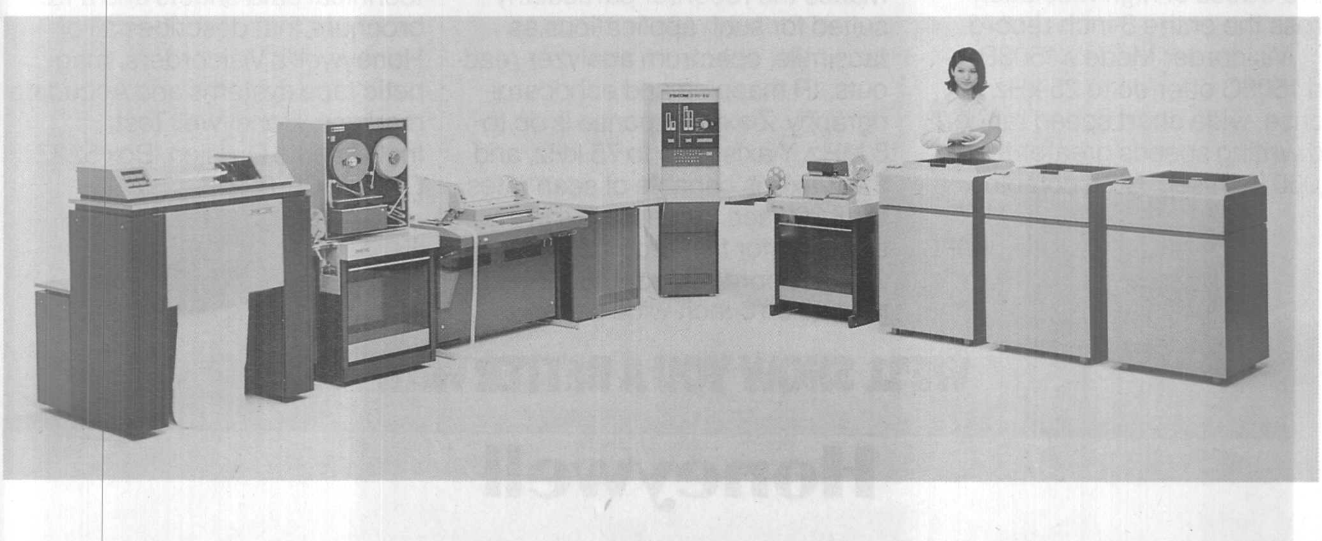
Despite its success in competing with IBM in the timesharing technique, GE found itself spending enormous sums of money on technical development and on financing customers' leases of equipment. GE left the computer business in 1970, selling its assets and installed base to Honeywell Information Systems.

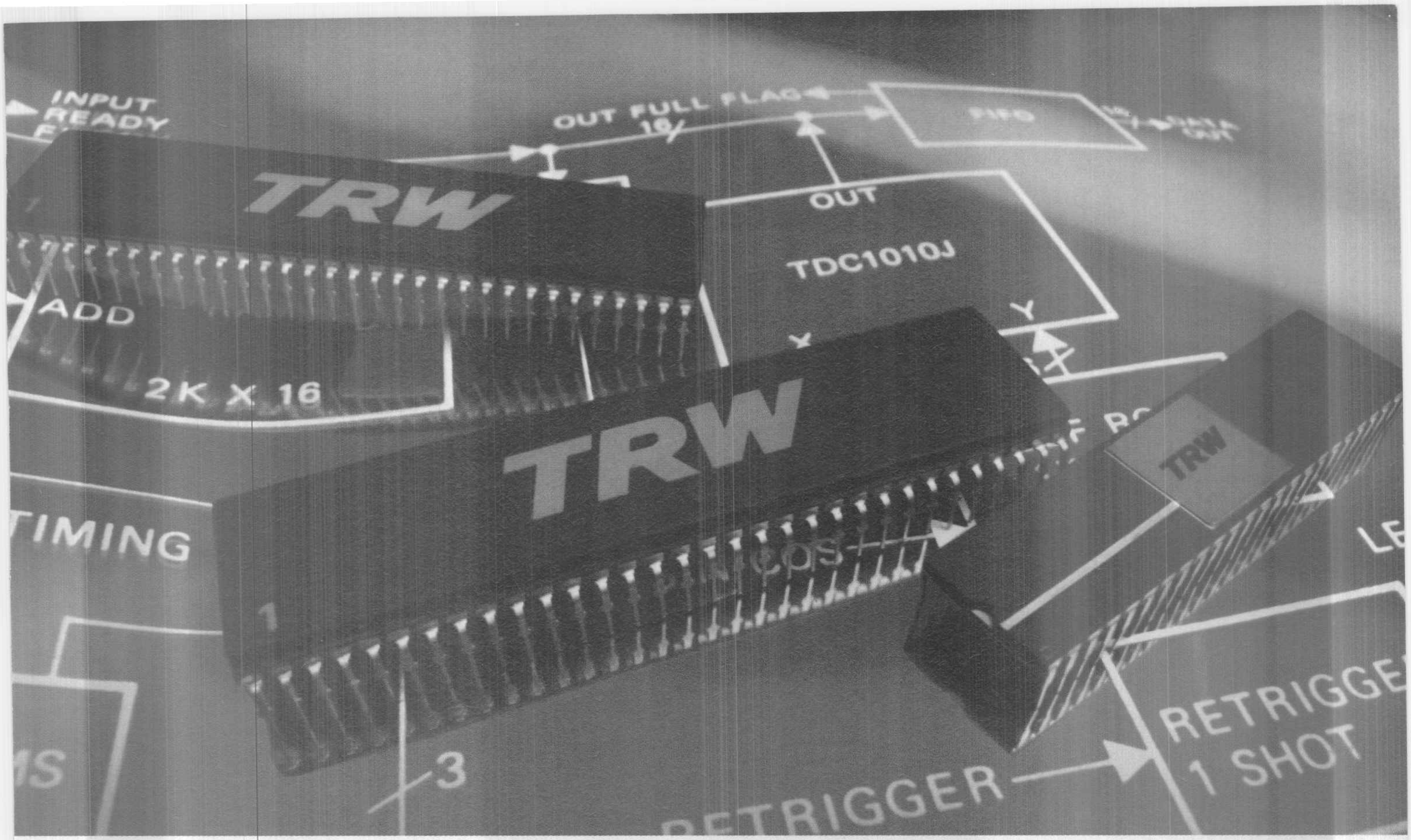
RCA, a pioneer in broadcasting and components making, did not enter the computer business until 1958 with its model 501. To this it added the 301 and 601 in 1960. The New York–based company's most dramatic computer announcement, however, came in December 1964 when it tried to go IBM one better by announcing its Spectra 70 family of computers, based entirely on monolithic integrated circuits instead of the more conservative hybrid technology chosen by IBM. RCA bought its components from Fairchild Semiconductor.

Stressing compatibility, RCA announced that the Spectra 70 computers could run programs from the company's own 301 and 501 computers as well as IBM's System/360 line. The Spectra 70 family was reported to sell well and was expanded to include a total of eight models by 1969. But the stiff competition forced the company out of the computer business by 1972.

One result of the change sweeping the computer industry during the 1960s was the birth of new compa-

From the Orient. Japan entered the computer market in a big way in the late sixties. One competitor was Fujitsu and its Facom 230 series. The machines in the series ranged from the multiprogrammable model 60 down to the smallest model 10, shown here.




INPUT
READY
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OUT
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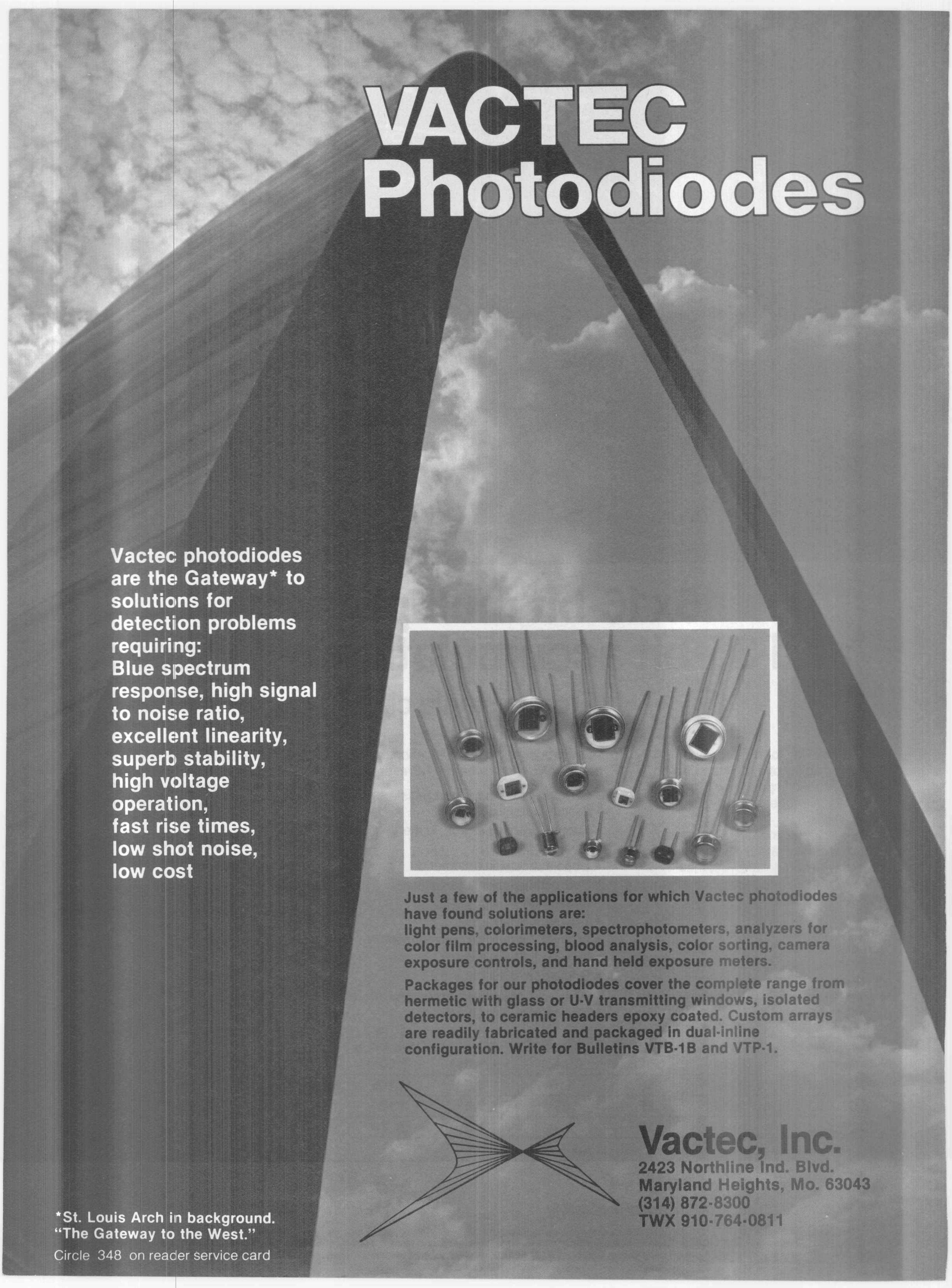
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nies formed to bring new technologies to market. Digital Equipment Corp. in Maynard, Mass., is generally credited with creating the market for the minicomputer with the introduction of its Programmed Data Processor model 8, or PDP-8, in 1965. The PDP-8 had a word length of 12 bits and a capacity of up to 4,096 words of memory. It was the first mass-produced computer and the first to sell for less than $20,000.

Gordon Bell, one of the designers of the PDP-8 and now vice president of engineering, recalls today that the eight-year-old company "was convinced that short-word-length, high-speed machines were needed."

"We built them," he says, "in such a way that other people could use them easily in real-time applications, and we worked a lot on the interfacing so it would be easy to attach other equipment to the unit."

Clearly a distinguishing factor of the new minicomputers was the way they were sold. Instead of legions of support personnel, DEC customers got a minimum of hand-holding. But the customers were primarily engineers and scientists who were using the devices for industrial systems or experiments.

DEC introduced an integrated-circuit version of the PDP-8 in 1967. The mainframe 36-bit PDP-10 came in 1969, and by then the company was fifth in the industry in computers installed. Most significant, however, was the introduction of DEC's PDP-11 line in 1970. It was based on innovative hardware architecture, centered on a single bidirectional asynchronous bus. All processing, memory, and input/output elements were connected to this bus, allowing the computer to be modularly configured in accordance with the user's specific needs.

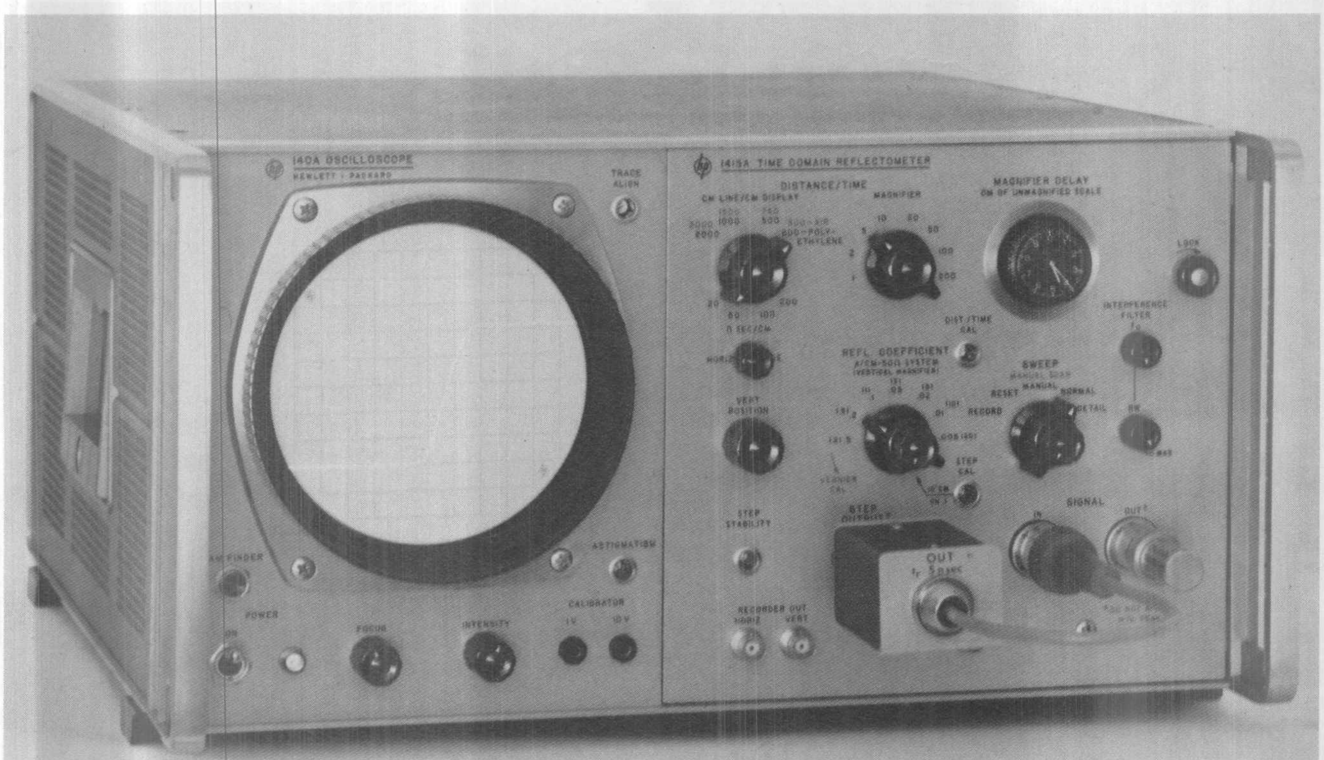
A number of companies followed DEC's lead into this new, small-computer technology. One of the first was Hewlett-Packard Co. of Palo Alto, Calif., which in 1966 introduced its model 2116A instrumentation computer and a year later its 16-bit general-purpose model 2115A.

And just as computer families begat other computers, so did computer companies beget other computer companies. Most notable of these spinoffs was Data General, founded in April 1968 by three ex-DEC designers. Their first product, called the Nova, was introduced that September.

The new machine was priced at $8,000 and offered a large computer's features – such as four accumulators, equipment previously unavailable in minicomputers. The Nova also allowed read-only memory to be mixed and matched with random-access memory up to the maximum of 32,000 words. This allowed important programs to be stored on the indestructible braided-core ROM.

Twenty-seven months after the Nova was unveiled, Data General introduced the Supernova, which operated between five and 15 times faster than its predecessor. The line was further expanded in October 1970 with the Nova 1200 and Nova 800 models and the Supernova SC, the first minicomputer to use semiconductor memory.

Seeing the potential, a number of concerns sprang up to offer minicomputers. Among these were Computer Automation and General Automation, Interdata, Modular Computer, Microdata, Datacraft, and Varian Associates. Old-line concerns countered with products of their own. Honeywell, for instance, introduced its



Reflectometry. In the early sixties Hewlett-Packard entered the oscilloscope marketplace with a series of innovative designs. For example, it introduced a time-domain reflectometry unit for making characteristic measurements of microwave systems.

Computer designers had grown accustomed to using a teleprinter for input and output by people, the most popular being Western Electric's teletypewriter. But during the 1960s the more versatile cathode-ray-tube terminal was developed and gained popularity.

Originally there was concern that the raster-scan tubes, like those in TV sets, would be difficult to use because the wide bandwidth required for the video signal could not be accommodated on telephone lines. In addition, much conversion was needed between the digital information produced by the computer and the analog deflection and intensity-modulated signals needed for the TV-like tubes. By the end of the decade, however, IBM, RCA, and Philco-Ford's Western Development Laboratories were perfecting such terminals.

Another new input/output device devised during the 1960s was a replacement for the ubiquitous punched-card machines. Mohawk Data Sciences Corp., a small company in upstate New York, introduced in 1965 its model 1101 data recorder. The operator used a keypunch-style keyboard, but instead of punching holes in paper cards, recorded the information on seven-track magnetic tape at 200 bits per inch for later processing by a computer.

Along with better input/output terminals came improved techniques for connecting remote terminal equipment to a central computer. By 1963 AT&T's Bell System had installed some 5,000 Data Phone modu- information over the analog voice telephone lines, and Western Union's Telex was in 3,000 locations for data transmission over telegraph lines.

To simplify the interconnection of digital input/output devices, communications circuits, and computers, the computer industry adopted the American Standard Code for Information Interchange (ASCII) in July 1963. Its 7-bit code represented the alphabet, numerals, punctuation marks, and transmission control characters.

By the end of the decade a number of companies were looking to get a share of the growing data-communications business by operating special digital transmission equipment. Among these were the Data Transmission Co., better known as Datran, and Microwave Communications of America. American Telephone & Telegraph Co. joined the pack in 1970 with a proposal for a digital private line service.

Standard programming languages, especially Fortran and Cobol, were well on the way to becoming accepted at the beginning of the 1960s, and several other key languages were developed during the decade. Kenneth E. Iverson of IBM gave the world APL in 1962. Although this symbolic language was helpful in certain programming applications, its special symbol notation made it difficult to use. In 1963 the IBM users' group, Share, got together with the company to develop a language that would be good not only for mathematics, but also for alphabetic character manipulation, which was difficult to do in Fortran or Cobol. The result in 1965 was PL/1, a general-purpose language with the widest scope of any

Master. Precision glass negative containing circuitry patterns for 48 etched printed-circuit cards for hybrid logic was fabricated for the System/360 line. Here it is inspected by a technician in a clean room before being inserted in an automatic photo-exposure machine.

language that had been created to date.

Meanwhile at Dartmouth College problems in teaching computer programming to large numbers of college students led to the search for an easier language. The result was the Beginner's All-Purpose Symbolic Instruction Code, or Basic, developed in 1964 by John G. Kemeny and Thomas E. Kurtz.

Algol, the programming language first compiled by the Association for Computing Machinery in 1958, was revised and improved during the early 1960s. The language was the first to use a block structure and defined the scope of variables better. It spawned a number of other specialized languages.

By now the American computer industry was firmly entrenched as the world's leader. IBM dominated the foreign markets as much as it did the American. The British industry, which had 12 computer manufacturers at the beginning of the 1960s, underwent a shakeout, leaving it with one major manufacturer by 1970—International Computers Ltd. France's one major computer maker—Compagnie des Machines Bull—received a major infusion of American capital, as did computer companies in Italy and West Germany. The only country outside the U. S. to maintain a position of independence and strength in the computer industry was Japan, which was prodded by its government into grouping its companies and teaming its efforts.

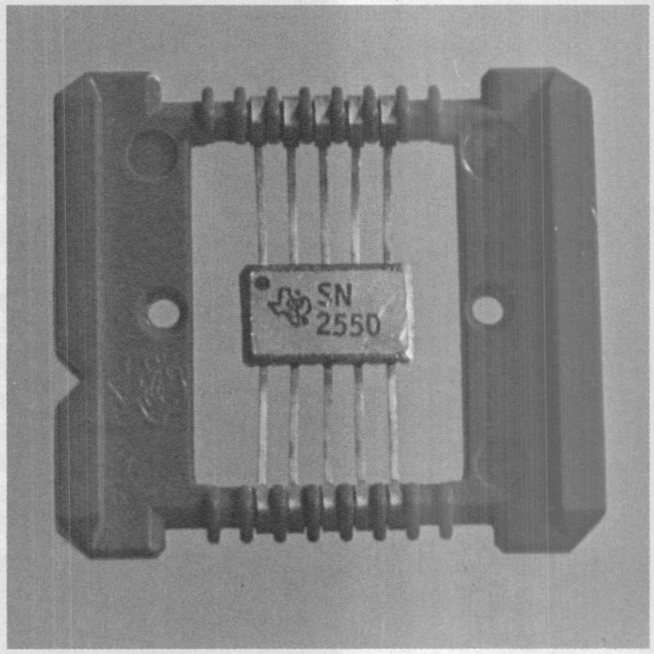
"Japan jumped from nowhere to third place in the world computer industry in six years, ranking behind the United States and West Germany in computer installations," said Katsuhiko Noda, chief of the Electronic Computer division of the Electrotechnical Laboratory in the Japanese Ministry of International Trade and Industry, in the June 27, 1966, issue of *Electronics*. Seven companies were involved: Hitachi, Fujitsu, Nippon Electric, Toshiba, Oki Electric, Mitsubishi Electric, and Matsushita. In 1961 the government created the Japan Electronic Computer Co. to purchase computers from manufacturers and lease them to customers, freeing the makers from the burden of supporting rentals.

Although Japanese computer makers had no trouble with the hardware, the critical software and the lack of trained personnel forced most to produce American computers under license during the early 1960s.

By 1966, however, the Japanese government aimed to make the companies independent of computer imports. Half of the estimated $190 million in computers to be installed in Japan that year were expected to be domestic. And the Ministry of International Trade and Industry drew up a $37 million five-year plan for research and development of a large, high-speed computer.

Fujitsu promoted Japan to the big leagues of data processing in 1968 with the announcement of its Facom 230 series. The model 60, introduced in April, was a multiprogramming computer that could be attached to another model 60 to create dual-processor configurations. Other models were added later that year.

In the Netherlands, Philips Gloeilampenfabrieken, the largest electronics company outside the U. S. during the 1960s, established a computer division in 1962. It introduced its first computers six years later. Three third-generation machines in the P1000 series were roughly comparable to the IBM System/360 models 30, 40, and 50.



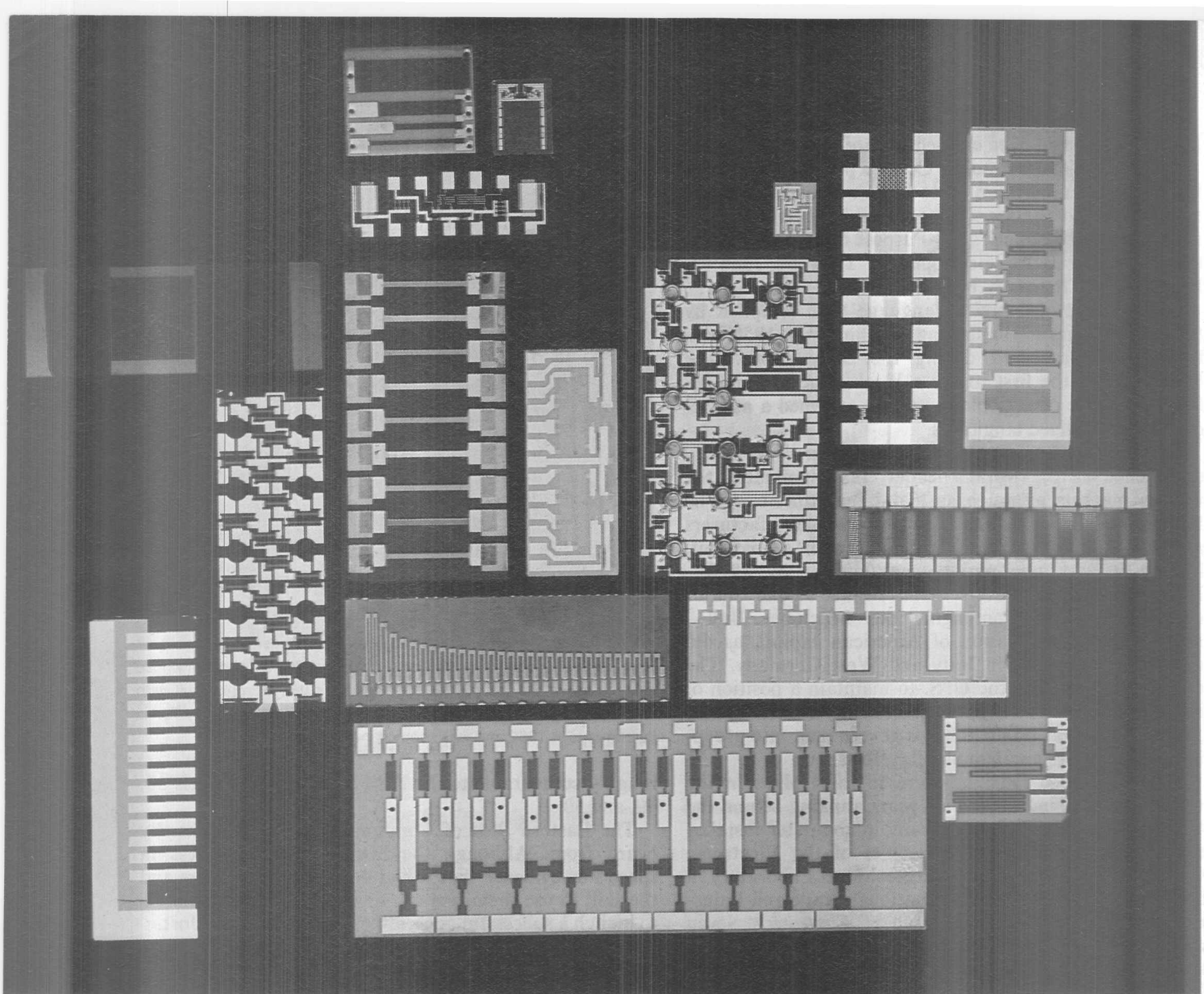
Flat pack. Handling tiny integrated circuits was a problem whose solution lay in the flat pack—a ceramic, plastic, or metal unit with flat-ribbon leads jutting from opposite sides. It was invented by Texas Instruments in 1962 and was soon an industry standard.

The Eastern Bloc of Communist Europe was hardly heard from. Although the Soviet Union's success in space was evidence that it had developed computers and the skill to use them, the country was apparently unable to launch a successful general-purpose computer effort.

Computers, of course, fanned the brushfires of automation that swept through the industrial world in the sixties. The National Biscuit Co., for example, bought a Foxboro digital computer to oversee the baking of Saltine crackers and Oreo cookies in its Chicago plant. In April 1961 control of a British chemical plant was turned over to a solid-state Argus 1024 computer by Ferranti Ltd. The following year, at the annual conference and exhibit of the Instrument Society of America, two speakers reported the use of Minneapolis-Honeywell 290 and IBM 1620 digital computers to control American steelmaking furnaces.

While more and more computers were turning up on production lines in 1964, and while engineers were awaiting the next big event in industrial electronics—the debut of integrated circuits in control computers—an important new control concept burst onto the scene: direct digital control (DDC) of industrial plant processes, a technique that timeshared one special-purpose digital computer among hundreds of transducer inputs and actuator outputs, was hailed as a breakthrough in simplicity and cost.

Not only was DDC control hardware cheaper than hundreds of dedicated analog single-loop controllers, it also did not require nearly as much time and money for programming as did the general-purpose mainframe



Shapes and sizes. Hybrid circuits in a striking variety of sizes, shapes, and colors were developed for the new miniature electronics. Different colors in these 1967 tantalum thin-film circuits from Bell Telephone Laboratories result from different thicknesses of tantalum oxide.

computers, intended originally for data processing. What's more, the new technique permitted plant engineers to optimize a process while the computer controlled it.

The only question about DDC was its reliability: would the whole process shut down if the computer failed? Experts agree that prevention of such an unacceptable event required computers with a reliability of 99.95%.

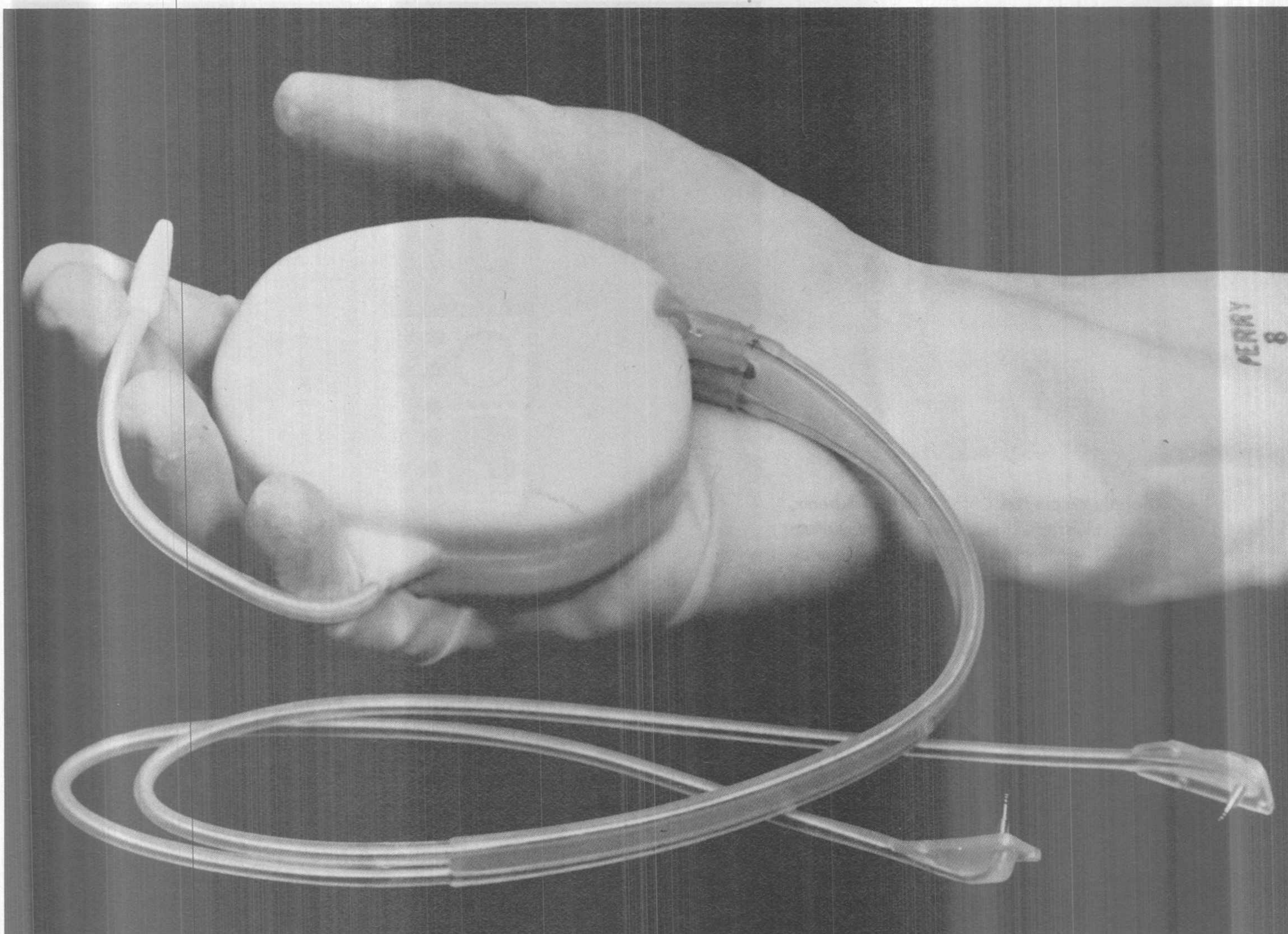
Seven companies led by 3M Co. soon had DDC systems on the market, all claiming computer reliability of 99.95% or better. Prices were well below those of the general-purpose industrial-control computers. One new system, the SDS-92 by Scientific Data Systems Inc., even pioneered the use of off-the-shelf AND/OR logic ICs for the input/output storage registers in its analog-to-digital converter. The cost of the SDS-92, with 2,000 words of memory, was $29,000.

America's largest industrial employer, the automotive industry, embraced computers. By 1964 General Motors and Ford were using computer graphics to create perspective drawings of new car models in real time. These drawings were then fed, on punched tape, to a numerically controlled machine tool that made mockups and actual parts dies.

The auto industry and the aircraft industry were the first to use numerically controlled inspection machines to check the position and to measure the size of holes in engine blocks. These boredom-proof inspectors cut quality-control times by 98%, even while documenting their own work.

Computers penetrated other markets, too. They landed jobs in power plants as training simulators, power-flow controllers, and data links for utility companies thousands of miles apart.

Industry began to explore the use of semiconductor devices as cheaper and more reliable replacements for mechanical and electromechanical hardware. For measurement of position, pressure, and velocity, semiconductor diodes, tunnel diodes, and Hall-effect diodes rapidly made inroads in markets previously dominated by potentiometers, synchros, and accelerometers. Typical of the new devices were new semiconductor strain gauges made of single-crystal p-type silicon; they were 10 to 100 times more sensitive to stress than were metallic or foil wire



Lifesaver. The miniaturization of electronics brought by the integrated-circuit revolution made possible this implantable heart pacemaker developed by Medtronic Inc., Minneapolis, in 1967. As the years passed, the progress in circuit integration would lead to even smaller units.

gauges. In another industrial use of electronics, ultrasonic generators with frequencies in the 20-to-100-kilohertz range cleaned tanks, drilled, welded, and soldered. Power-conversion techniques also improved.

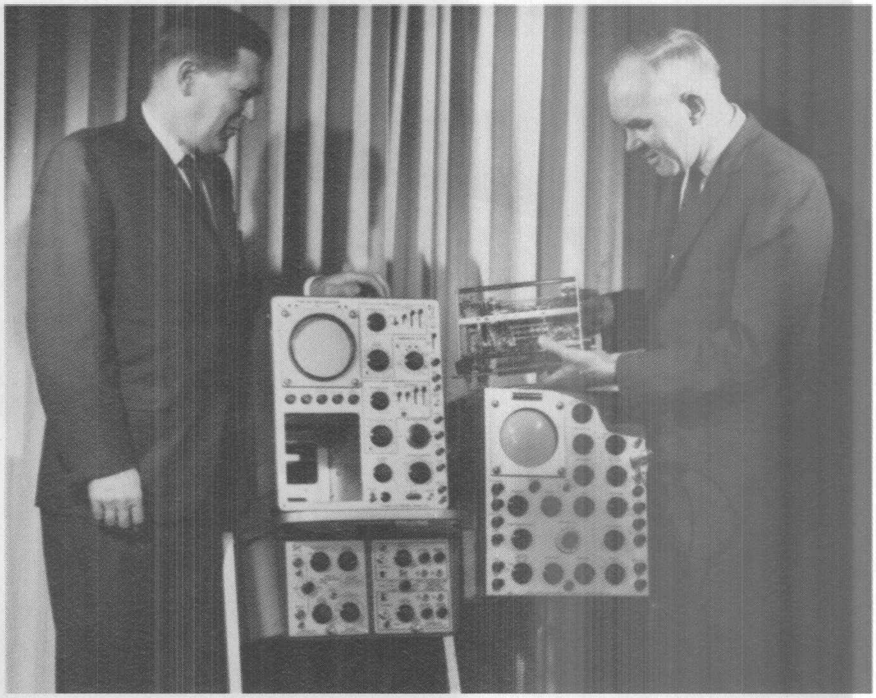
Silicon controlled rectifiers had been invented in 1956 by communications engineers at Bell Telephone Laboratories. They used them as "pnpn transistor switches." But power engineers, led by Gordon Hall at General Electric's rectifier plant in Clyde, N. Y., developed SCRs into cheap, reliable devices that could control large amounts of electric power.

Video technology improvements brightened the future of that field. High-resolution vidicon cameras inspected the radioactive interiors of nuclear power plants. Cathode-ray tubes and computers joined forces in photocomposition systems that eventually spelled obsolescence for hot type in the printing industry. Similarly Ampex Corp. started the clock ticking for movie films in broadcasting with its 1967 introduction of a computer-based color video disk recorder that sold for only $5,000.

Components other than semiconductors had come a long way by the end of the 1960s. The decade had opened with a technology based on tubes and transistors; it ended with linear and digital integrated circuits laying the foundation for the microelectronics revolution of the seventies (see Chapters 5 and 8). A list of significant component developments would have to include:

- The creation of new families of IC packages ranging from beam-lead and flip-chip to the familiar flat-pack and dual in-line versions.
- The emergence, in response to new semiconductor devices, of families of miniaturized passive components plus modular operational amplifiers.
- The birth of components for optoelectronics—light-emitting diodes, fiber optics, optical couplers.
- The arrival of additive technology for printed circuits and heavy use of the multilayer pc board.
- Continued emphasis on automatic assembly and automatic wiring.
- Heavy stress on thin-film and thick-film hybrid circuitry for packaging.

One of the most important improvements in IC



Fondly displayed. Cofounders of Tektronix, Jack Murdock, left, and Howard Vollum showed off their new 500-series of general-purpose oscilloscopes in 1964, 17 years after launching the first of the series, the 511. Shown is the 547, which promised crisp display, reliability, and sophistication.

processing was the adoption by semiconductor makers of ion implantation—a technique for modifying the properties of solids by implanting them with ions. The idea had been pioneered in the late 1940s and early 1950s by Russel Ohl and William Shockley of Bell Telephone Laboratories.

Ion implantation was being used in 1963 to make solar cells at a plant of the Ion Physics Corp. in Burlington, Mass. One of the first commercial implanters was reported in 1967; it was made by the same Ion Physics Corp. By 1970 ion implantation was ready to go into the process lines of Hughes and Mostek.

Another important IC fabrication advance was the creation of "clean rooms" to cut contamination of the silicon wafers by dust and other particles. These began to be installed in 1967 by General Instrument, Texas Instruments, American Microsystems, and RCA. The rooms had only one to 100 particulates per cubic foot of air and were the forerunners of today's super clean rooms, which have proved to be so necessary for large-scale integration.

An article in the July 8, 1968, issue of *Electronics* described Signetics' use of plasma (a cloud of charged ions) to strip resists from silicon wafers. This technique, a dry etch, became heavily used in the late 1970s for processing large-scale integrated circuits. Another short article in 1969 described a photoresist coater that moved wafers on an air curtain. This technique, designed by Industrial Modules Systems of Cupertino, Calif., was also to reemerge in the late 1970s in fully automated in-line IC processing facilities.

IC lithography methods that were to figure in planning for very large-scale integration in 1980 got their start in the 1960s. A parallel effort was the development of both the IC pattern generator and step-and-repeat camera—both of which were used to make precise masks for ICs. X-ray lithography, another important technique, did not appear until 1970.

Mask-making, the stimulus for all the lithographies, rapidly became so complex that circuit designers started going to computer-aided design. In 1964 the Norden division of United Aircraft used the technique to do a design analysis and mask layout for a linear microcircuit (a two-stage differential amplifier). The Norden system was centered on an interactive CRT terminal where changes could be made with a light pen.

By 1969 computer-aided design for ICs was in universal use. Computers were now doing everything from turning out logic equations to printing out instructions for fabricating ICs. The use of stored cells (standard subcircuits), partitioning logic, and computer-generated art work became standard.

As the IC evolved, problems arose in attempts to connect the tiny chips to either hybrid or printed-circuit substrates. Packages that were developed for pc boards were the flat-pack, dual in-line, and quad in-line. To attach a bare chip to a hybrid, the following techniques were devised: flip-chip, beam-lead, and spider-bonding.

The first IC package to appear was the flat pack, a ceramic, plastic or metal unit with flat ribbon leads coming out of two opposite sides. Invented at Texas Instruments in Dallas in 1962, it was quickly accepted and standardized, and in 1965 TI developed a socket for use with it.

The dual in-line package, a rectangular ceramic or plastic unit with two rows of pins on 100-mil centers, originated in 1964 at Fairchild Semiconductor in Mountain View, Calif. And in Anaheim, Calif., in 1969 Autonetics, then a division of North American Aviation, designed an interesting variation of the DIP that reap-

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peared late in the 1970s. This was a 42-lead ceramic package with a staggered lead frame that accommodated two rows of pins on 50-mil centers on each side. This has since become known as the quad in-line package.

The flip-chip method of attaching chips to hybrid substrates was first discussed in a 1963 paper from IBM. It proposed that large metal bumps, or balls, be built up on the contact pads of a transistor or IC. The device could then be mounted face down to conductors on a ceramic substrate and reflow-soldered on. Many companies experimented with this method, but from 1970 on, it was almost exclusively used by IBM.

In the beam-lead method, pioneered at Bell Telephone Laboratories in 1964 by Martin Lepselter, a gold metalization system not only interconnected individual gates of an IC chip but also provided beam-like leads to connect to external circuitry. The gold lead was relatively thick and extended beyond the boundaries of the chip like a cantilevered beam to contact the substrate's pads.

The beam-lead process proved to be extremely reliable, and for a while TI and Motorola made commercial beam-lead chips. In time Western Electric became the main advocate of the technology, using it to make its own ICs, in the same way that IBM took to flip chips.

Spider bonding was unveiled in 1968 by Motorola as its way of eliminating wire bonding of the die to a lead frame. A special machine was used to bond the chips to a spiderlike pattern stamped out of a continuous strip of metal. Meanwhile another machine automatically welded the spider-bonded dice and leads to a lead frame. All bonding was done at once, making the process 20 times faster than manual bonding. This process was used by Motorola into the early 1970s but was eventually superseded by more conventional methods like automatic wire bonding and later tape automated bonding.

Tubes started strong in the sixties and gradually faded. There was still kick in the tube industry in 1961. News stories that year mentioned companies using General Electric's Compactron (several tubes under one envelope) for either TV or stereo applications. A new radar beacon in 1961 used the Nuvistor, a small ceramic tube made by RCA (see Chapter 6). The transistor and a zener diode were available, but not without limitations.

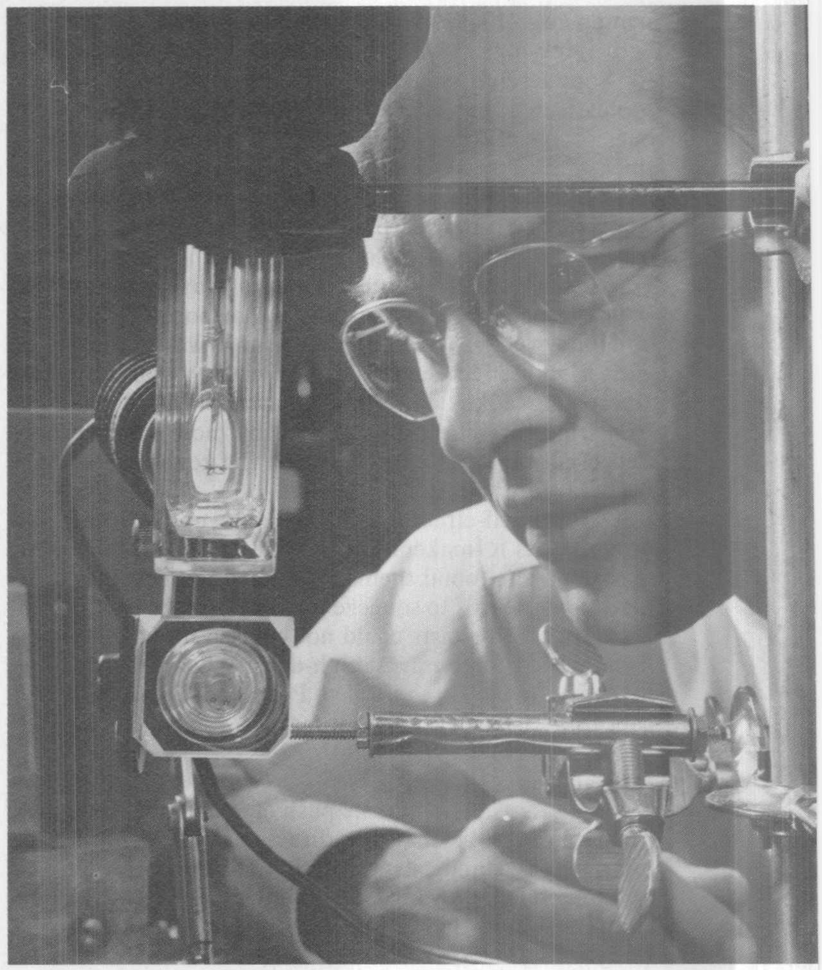
Tubes were still being considered for circuit design in 1963. RCA, for one, thought enough of them to pour \$11.6 million into expanding its tube plant in Lancaster, Pa. However, except for specialized high-power transmitter tubes and replacement tubes for existing equipment, the tube was through for all practical purposes by the decade's end. Silicon devices did it in.

During all this activity, manufacturers of passive and even electromechanical components were not standing still. Miniaturization of resistors for high-density packaging was reported in 1964. The new mini types were mainly films—deposited carbon, metal, and tin oxide. Meanwhile thin films of Nichrome or tantalum were serving as precise resistors on hybrid substrates.

Relays became smaller and faster. Types like the miniature rotary armature, sealed reed, ferreed, tuned reed, and mercury-wetted relays emerged in either crystal cans or sealed glass tubes. All could be driven either by a transistor or by certain digital ICs. By 1969, C. P. Claire of Chicago was advertising a relay small enough to fit into a TO-5 transistor can. Inductive devices such as transformers and chokes began to use the now-familiar ferrite core in the move toward size reduction and higher-frequency operation. Tiny cores could be used to make inductors 1/1,000 the size of previous commercial inductors.

Potentiometers were very much in the picture in the 1960s, since most circuitry was analog and servomechanisms required mechanical feedback elements. Wirewound, cermet, conductive plastic, carbon, and metal-film potentiometers were all in use. Miniaturized versions were used for trimmer applications. Trimmers were now designed to be mounted on a pc board rather than a front panel.

Another important trend of the time was modular components. Companies like Teledyne/Philbrick, Analog Devices, and a host of others came out with small epoxy-coated modules for plugging into pc boards. These modules were mainly high-performance operational amplifiers and a few data converters. Also, some



Laser. General Electric in 1962 had a new type of laser, one made of gallium arsenide, seen as a small spot between two electrodes within the circles at the lower end of the photograph. Robert N. Hall peers at his discovery, which was cooled in liquid nitrogen.

companies—Beckman Instruments, for one—came out with thick-film hybrid amplifiers and voltage regulators for commercial use. These hybrids could be extremely sophisticated. For instance, in 1968 Philbrick/Nexus put out an operational amplifier in a flat pack, using a thick-film interconnect and thin-film resistors on an alumina substrate. Thick- and thin-film technologies were, in fact, often combined in hybrid designs.

One of the cleverest components of the decade was a Hall-effect key switch—a solid-state contactless switch—made by Microswitch, a Freeport, Ill., division of Honeywell. The heart of this unit was a special IC with a Hall-effect sensor, trigger circuit, and amplifier. Depressing a key lowered a magnet near the device, triggering it. This key switch, by now considerably improved, remains in heavy use on the keyboards of data terminals to this day.

The printed-circuit industry kept up with all the progress. As IC makers went to flat packs and then DIPs, the pc makers found themselves going to finer lines or to multilayer boards to squeeze more DIPs on boards.

Screened-on resists could not be used to make the fine lines needed for the new high-density boards. Dry films filled the need. By 1970 Du Pont and Dynachem had captured 21% of the pc resist market.

The push of instrument designers in the 1960s was in three directions: the definition of more precise standards, the design of new instruments to accommodate growing use of telemetry and digital computers, and the design of automated testers for new integrated circuits.

In 1961 electronic measurement precision took its first great leap of the decade. The National Bureau of Standards applied the electrostatic theorem introduced by A. M. Thompson and D. G. Lampard in Vol. 177 of Nature in 1956. The theorem covered the construction of capacitors whose values could be computed if a single parameter—length—was known precisely. The capacitor developed by the bureau made measurement of resistance simpler and more precise.

Using a special quadrature bridge, R. D. Cutkosky of the bureau compared capacitance and frequency to an ac resistance and transferred this measurement to a resistor whose ac/dc difference was calculable. His measurement uncertainty was only 2.3 ppm.

Once instruments could be calibrated easily to more precise electrical standards, NASA and the military could reasonably require their suppliers to use instruments calibrated against standards that could be traced to the National Bureau of Standards. In 1962 this requirement was rigorously imposed by the Government.

The next great improvement in standards came in 1964. The International Committee on Weights and Measures abandoned difficult-to-measure ephemeris time (based on the earth's orbital revolution around the sun) and adopted the standard based on the work of Jerrold R. Zacharias of the Massachusetts Institute of Technology in the 1950s—atomic time. A second of atomic time is defined as the period in which an electron in the shell of a cesium-133 atom, undisturbed by external fields, makes 9,192,631,770 transitions between two specific energy levels.

Again, the new standard was critical for the U.S. Government. What was to become the nation's first line of defense, the Polaris submarine, was based on the ability to measure frequency and time precisely, so that the submarine crew could determine their position precisely before aiming and launching a missile.

The great emphasis on rocketry, not only for defense but also for global communications and the exploration of space, also brought telemetry to the forefront. The burgeoning amount of data to be transmitted put a burden on the existing fm/fm telemetry system. At first, the density of data was reduced by processing the data before transmission, so that only changes in the measured value were transmitted. This reduced the power needed in the transmitter, saving space and weight, but soon even this proved insufficient, in terms of not only data density but also data accuracy.

To overcome these difficulties, various pulse transmission techniques were tried with which data could be packed more efficiently. Pulse-code modulation was found to be most efficient.

As a result of the space program, two demands were placed on the instrumentation industry in addition to the need for higher accuracy: to make small sensors to measure a variety of physical parameters, and to provide instruments that could feed measurements directly into a computer. Echoing these demands were the utility and process-control industries, which found telemetering a boon to the management of their facilities, and also the field of medicine, which sought to detect conditions within a patient's body.

In 1960 the Lockheed Missiles and Space division developed a 3-ounce fm transmitter that a patient could wear around his neck while performing routine work. Data from body electrodes was transmitted to an fm tuner to drive a conventional electrocardiograph. Gulton Industries developed an electronic thermometer that used a thermistor in an ac bridge to provide quick temperature measurement. And in 1961 Gulton developed a system for the Air Force that could measure 14 different physiological parameters.

There were other developments, too. Dr. D. H. Howry and Dr. J. H. Holmes of the University of Colorado developed the Somascope, which produced a two-dimensional picture similar to an X ray on an oscilloscope by using ultrasound at a rate of 1,000 pulses per second. A pressure-sensitive radio pill was built by AIL for measuring conditions in the gastrointestinal tract.

Implantable pacemakers were developed by doctors at the University of Buffalo. The Veterans Administration hospital in Buffalo, together with Wilson Greatbatch Electronic Consultants and Medtronics, were licensed to manufacture and market them.

The explosion in information that was taking place called for faster analysis, and this meant getting the data in a form that could be accepted by a computer. The answer was digital instrumentation whose design was

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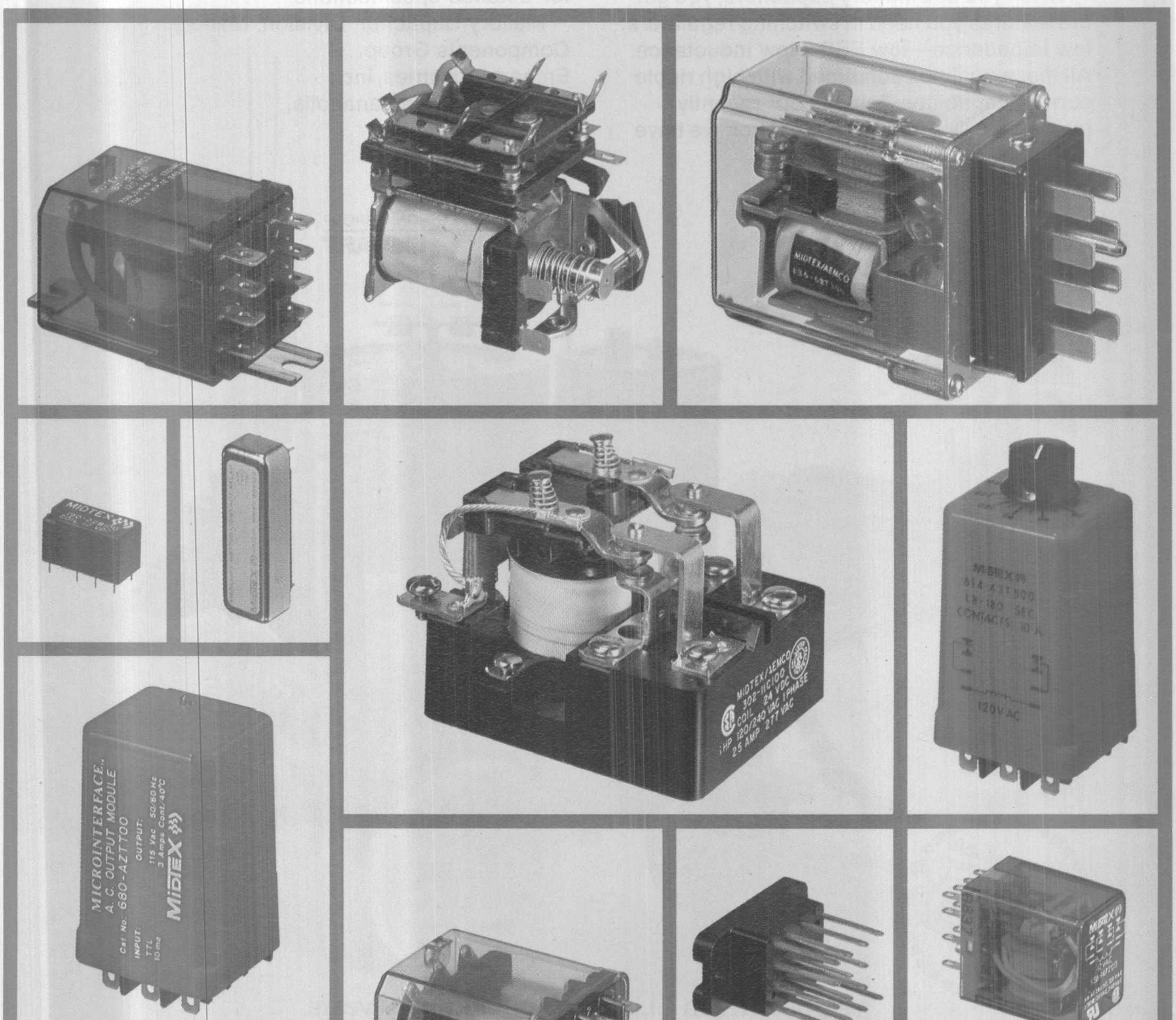

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Camera. RCA's four-tube color TV camera, the TK-42, was introduced at the 1962 National Association of Broadcasters meeting. A $4\frac{1}{2}$-inch-diameter image orthicon, shown, handled the monochrome channel. Color pickup was with 1-inch image orthicons.

based on the binary counter. Such instruments were more complex than analog instruments and therefore more expensive. But they were also more accurate.

Early digital instruments relied on a variety of display techniques, such as optoelectrical and optomechanical numeric devices and even electroluminescent ones. The Nixie tube, used in Andrew Kay's first digital voltmeter (see Chapter 6), was by far the most popular display, but 1968 was to mark the beginning of its decline. That year Hewlett-Packard unveiled the first commercially available light-emitting-diode matrix, a 28-diode unit developed by the company's components group.

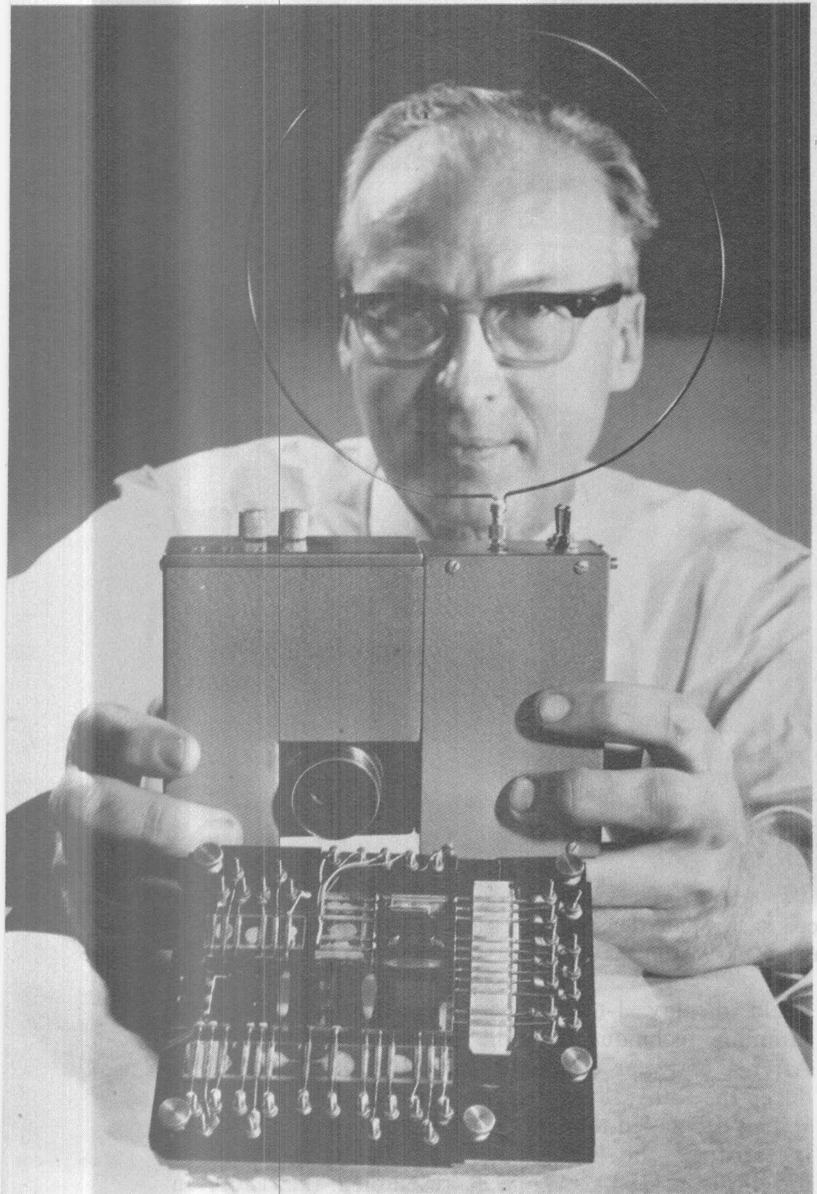
A number of different DVM measurement techniques were also developed at about this time: ramp, integrating, and potentiometric-integrating. But the technique that was to become the standard for DVM design—because it removed errors caused by random noise and hence provided much more accurate results—was dual-slope integration. The technique was first developed by R. W. Gilbert of Weston Instruments in the 1950s but was not thought to be of great use at that time. In the mid-sixties George Armann of Fairchild Camera and Instrument developed refinements of the technique, and Weston and Fairchild shared the patents.

Tektronix dominated in scope sales, and its biggest challenger was Hewlett-Packard. In 1962 Tek introduced a direct-view bistable storage tube, the model 564. HP had a very high-speed oscilloscope, the 185A, which could display 1-GHz repetitive signals by using a sampling technique that the company had developed. After a two-year effort that began in 1964, HP introduced the 180A, the first solid-state oscilloscope.

This design led to an even stronger foray into Tektronix territory, the laboratory oscilloscope. In 1969 HP unveiled the 183A. While it resembled the 180A in appearance, it was the fastest direct-writing scope of its time.

Tektronix and HP met head on in 1969 at the Western Electronics Show and Convention. While HP was showing off the 183A, Tektronix was unveiling its new 7000-series laboratory scope. The Tek scope, which was also solid-state, had a bandwidth of 150 MHz, and written right on the screen were such things as sweep time and magnification and vertical sensitivity. This feature stemmed from a newly designed medium-scale integrated circuit. Rather than space for two plug-ins, like the 183A, the 7000-series had room for four, so that the dual-beam unit could provide separate vertical amplifiers and time bases for each input.

When the smoke cleared in the 1970s, Tektronix was still dominant in the scope business. But Hewlett-Packard, with its experience, developed other important instruments. It gained a valuable position in spectrum analyzers, first with the introduction of plug-ins for the 410A scope and later with the introduction of the 851A/8551A spectrum analyzer. HP also contributed to



Solid. In 1966 RCA displayed a tubeless TV camera, its electronics on the board in the foreground. Held here by Paul K. Weimer of RCA Laboratories, Princeton, N. J., the unit relied on 132,000 thin-film sensors deposited on four 1-inch-square glass slides.

engineering a measurement technique that is still important: time-domain reflectometry.

Noticeable in these and other instruments built in the latter 1960s was the use of integrated circuits. In 1966 the boom in ICs was heard around the world. Not only instrument makers, but everyone in the industry was using them, and so a new instrument market opened for automated equipment to check the parameters of ICs.

Teradyne of Boston was one of the first companies to commit itself to the production solely of automated testing equipment. In 1960 it built the D-131 diode tester. Texas Instruments in Dallas marketed the first IC tester that year, the $16,500 model 659A. It could perform 36 tests on devices with up to 14 pins. Teradyne then introduced the R105, a go/no-go automatic resistor tester that relied on dial-set tolerances. The tester was sold in quantity to a component maker, Allen-Bradley, and was a big success! Fairchild had an entire line of transistor testers, starting with the model 50 and progressing through the series 200, 250, 500, and 900.

The need for testing even by users was hammered home in 1969 when many customers who had relied on semiconductor manufacturers to provide good linear ICs were encountering failure rates as high as 1 in 100. By then there were good commercial testers, but under the pressure of intense competition, some IC manufacturers had relaxed their reliability standards. The problems were not found until customers had used the ICs in systems and then had tested the systems.

GenRad provided part of the answer the same year—1969—by introducing the first commercial IC board tester, the model 1790. Now manufacturers could test their boards before system assembly and reduce the cost of faults by a factor of 10. The other part of the solution was to have a forum in which users, test-set manufacturers, and the semiconductor makers could exchange frank views. At Cherry Hill, N. J., the first conference on automated testing was held in the fall of 1969.

An entirely new field of electronics came in with the sixties: optoelectronics. This was a blending of optical components (light pipes, lenses, fiber optics) with light-emitting and light-sensitive electronic components (light-emitting diodes, phototransistors, photodiodes). The result was unique components, such as the optical coupler, with tremendous electrical isolation from noise.

The first breakthrough came with the solid-state light emitter, or light-emitting diode (see Chapter 5). The LED was first thought of as a light source. "Will Gallium Alloys Provide a New Electric Light Source?" was the headline on a product article in the Dec. 28, 1962, issue of *Electronics*. But starting in 1968, LED displays became commercially available. By 1970 an optoisolator in a DIP was being sold by Monsanto, and from then on, optoelectronics started to move.

While the gallium arsenide injection laser was made to work in 1962, actual applications to systems had to wait almost to the end of the 1970s. Only then were fabrication and reliability problems overcome and the working specifications became such that the injection laser would be a natural choice for application to fiber-optical communications.

This laser was a perfect example of how scientific development can occur simultaneously in different laboratories. It was developed twice, at IBM and again at GE, which reported actual stimulated emission on Nov. 1, 1962, in simultaneous publications in the journal, Applied Physics Letter. To complicate matters, a paper was received by the same journal, on Nov. 5, 1962, from MIT's Lincoln Laboratory to announce its successful observation of GaAs emission.

While all this activity was stirring, solar-cell development was striding ahead. Space was again the spur—efficient, lightweight photovoltaic cells were needed to power satellites. By 1960, six years after their development at Bell Telephone Laboratories, single-crystal sili-

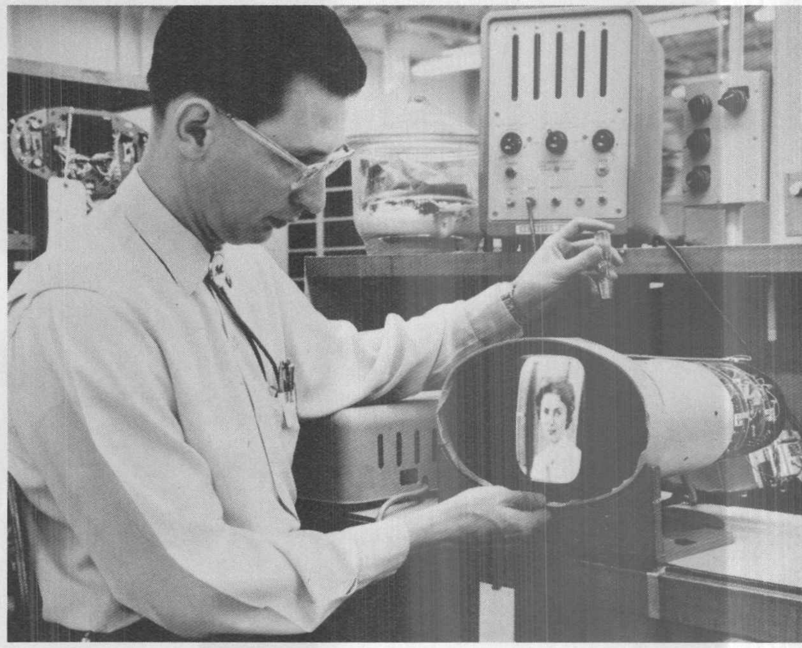
con solar cells had reached 8% conversion efficiency.

One of the slowest areas to join the trend to solid state was consumer electronics. At the beginning of the decade, color television was still struggling to become a feasible consumer electronics product; there were only 500,000 color sets in use throughout the U. S. in 1960. There were no home video tape recorders, no automobile stereo tape-cartridge or cassette players, and no solid-state wristwatches.

But by the end of the decade, all of these products had been introduced, ICs were turning up in more consumer electronics products, and there were dramatic improvements in color television sales and design.

Although the technical quality of monochrome TV broadcasts at the turn of 1960 was virtually perfect, such was not the case with color TV. In attempting to design a superior system, engineers constructed a number of prototypes, most of which never made it into the marketplace. Nevertheless the components and schemes that evolved from their efforts before the decade ended were used in the first generation of the U. S. color TV system as we know it today.

Color television sets did not begin to sell briskly until 1963 or 1964. Total sales topped 9 million in 1965, and the proportion of color sets to black and white by 1970 was more than 50%.



On the phone. AT&T thought it had a good thing when it introduced its Picturephone, shown here being checked in 1965 for picture size and quality at a Western Electric plant. But the set's high cost or lack of appeal or both served to keep it from catching on.

With an eye on the American market, the Yaou Electric Co. in Japan introduced a solid-state color set in June 1964. The set had a one-gun, 8-inch picture tube and no convergence circuits. Yaou's tube, developed by the Kobe Kogyo Corp., was an improved Lawrence type that used a color-switching grid to focus the electron beam onto a particular color strip.

The Yaou set notwithstanding, it seemed in 1964 that transistor color television sets were several years away. Fairchild Semiconductor designed and built an almost completely transistorized large-screen color set in 1966 to demonstrate that it was well within the state of the art; the only tubes were the high-voltage rectifier, the vertical-scan output circuit, and the vhf tuner.

In March 1966 RCA put the first IC into a television set; it performed amplification, limiting, balanced frequency-modulation detection and audio preamplification in the 4.5-MHz intercarrier sound channel.

In 1968 Motorola was placing the chassis of its color sets in slide-out frames; the chassis contained plug-in modules that a service technician could replace without soldering a single lead. In England, Thorn Electrical Industries Ltd. said it also would introduce an all-transistor color set that had plug-in modules.

Color television continued to improve. By late 1969 the first sets with electronic tuning came off assembly lines. RCA introduced a set tuned by signals from a hand-held ultrasonic transmitter. The receiver used a MOS FET's gate capacity to develop a voltage in a memory circuit arrangement to control color saturation, tint, and volume in response to a digital signal.

At the start of the sixties the Federal Communications Commission had spent over $2 million to test the feasibility of uhf broadcasts in a large metropolitan area. The tests used an antenna atop New York City's Empire State Building, but before they were complete, one FCC commissioner, F. W. Ford, proposed that all new TV sets moving in interstate commerce be equipped to receive uhf as well as vhf channels. Ford estimated that adding uhf would cost set makers about $10 a set.

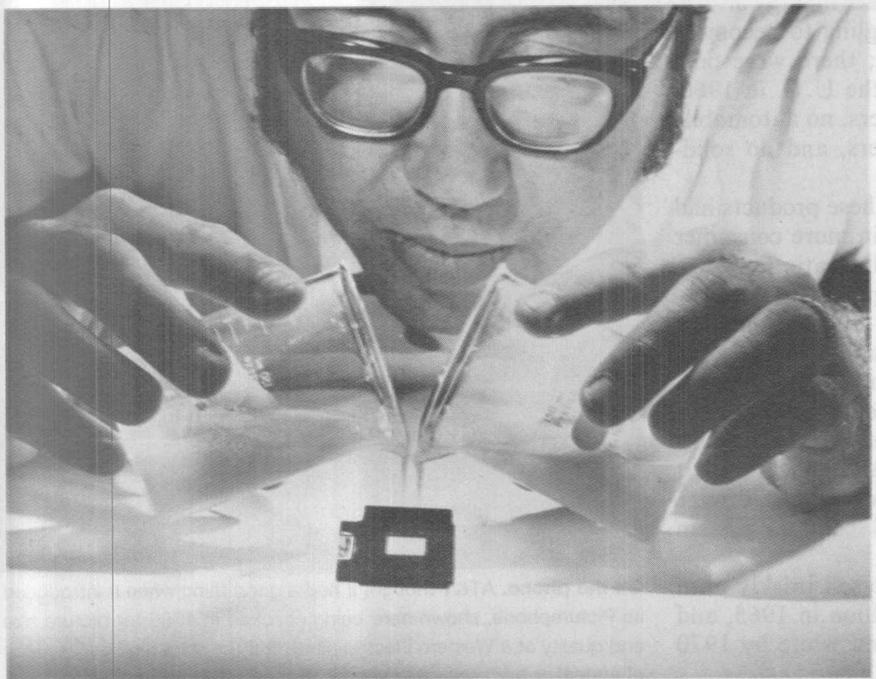
The Electronic Industries Association's Consumer Products division reacted negatively to an all-channel bill that was introduced in Congress. Manufacturers contended that it would penalize set makers and consumers alike with "dubious" results. FCC Chairman Newton N. Minow, however, pressured broadcasters to support the proposed legislation. The House passed the bill in May 1962, and the Senate backed it the following month. The law went into effect April 30, 1964.

Uhf-TV did not take hold initially. However, the number of uhf stations picked up in 1968.

In radio, stereophonic sound offered a way both to enhance reception and retain an audience in the face of increasing competition from television. Extending an idea introduced in 1931 by an English inventor for reproducing live concerts on a disk, Leonard B. Kahn, an engineer in New York, developed in the late 1950s the first system to handle stereo broadcasts.

The English inventor, Alan Blumlein, had used multiple sound channels in a way that recreated concert hall performance. Kahn's system placed both left and right stereo channels on an a-m carrier. Two receivers were required to demodulate the signal, one tuned to a frequency slightly above the main carrier, the other below it.

The first broadcasts came from Station CJAD in Montreal in January 1960, using a system that had been supplied by Kahn. U. S. manufacturers, sensing a major market, rushed to develop systems that might be



Alchemy. Liquid-crystal displays turned up in the sixties, promising low power and relatively large areas. RCA scientist Joel Goldmacher in this 1968 photo is pouring together two types of liquid crystal material to produce a quasi-emulsion that retains an image even after power is turned off.

accepted by the FCC. Similar stereo systems proposed by GE and Zenith were eventually accepted by the FCC, and on June 1, 1962, it approved stereo broadcasting.

The FCC had authorized fm broadcasting exactly a year earlier. The first two fm stations on the air were operated by the Zenith Corp. in Chicago and by GE in Schenectady, N. Y. By November 1961 there were 22 fm stereo stations on the air, with 50 forecast by the end of 1961 and 123 by the end of 1962. Manufacturers and distributors reported heavy demand for equipment, and the trend was to buy integrated fm stereo receivers rather than adapters for monaural sets.

Automobile stereo tape cartridge players began to appear in 1964. The original four-track cartridges were followed by more compact eight-track units. The first major marketing effort for cassette tape recorders began in 1966, and by 1969 audio tape recorders were, after color TV, perhaps the hottest item in consumer outlets.

"The cassette is not only challenging the Stereo 8 for leadership in home entertainment outlets," *Electronics* observed, "but is also going after the huge auto market. Panasonic is reported to be starting production of a cassette player for cars. By next year auto makers will begin offering the motorist a choice. When this happens, it seems likely that the industry will adopt the cassette exclusively within five years."

The forecast was wrong, primarily because so many Stereo 8 cartridge albums were sold that consumers continued to buy cartridge players.

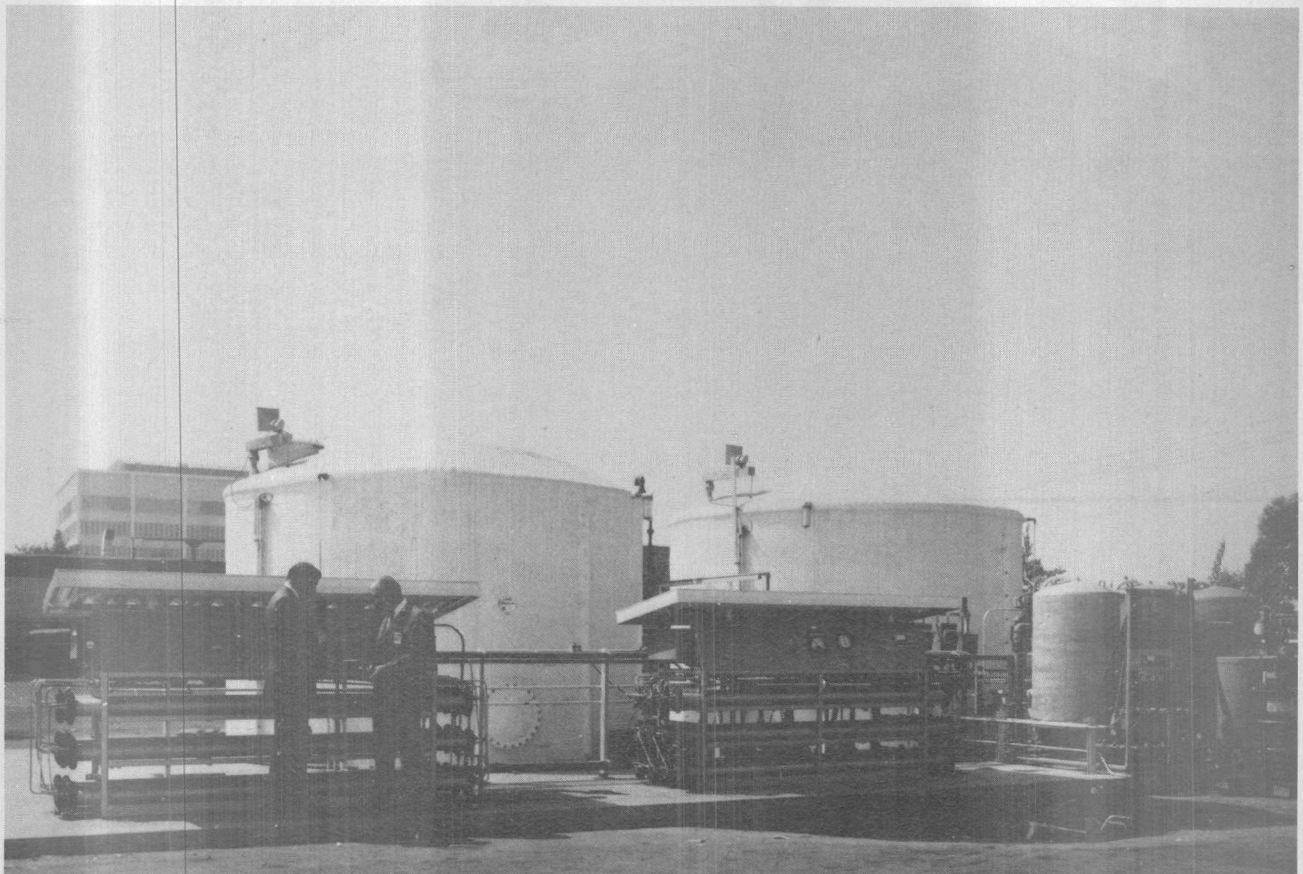
Although ICs were developed in the late 1950s, they did not begin to appear in consumer electronics until 1966. RCA showed the commercial feasibility of the microcircuit in an fm receiver in August of that year. The entire unit was built with four chips: one silicon wafer operated as a radio-frequency amplifier, another as a mixer-oscillator, a third as an intermediate-frequency amplifier limiter, and the fourth as an i-f amplifier, limiter, detector, and audio-frequency preamplifier.

Despite this show of confidence, the use of ICs did not catch on immediately in the TV industry. Nor was there a rush to add solid-state controls to large and small home appliances. One of the first appliances to use silicon controlled rectifiers was a Whirlpool laundry dryer introduced in 1963; the SCR provided continuously variable speed.

Perhaps the first use of an IC in a portable appliance was the cycle control in a John Oster Manufacturing Co. food blender. The appliance used a low-cost, plastic-packaged high-threshold-logic IC developed by Motorola's applications engineering department. The design eliminated push buttons and switches; the ICs formed a shift register. Microwave oven sales also grew through the 1960s, but slowly.

And so another decade slipped by, with electronics solidly entrenched in the business world and poised for new advances into the home. Already there was talk of expanding the family television set into an electronic information center. With a TV receiver and the proper peripheral equipment, one could get the news on demand or view store advertisements and place instant orders or perhaps conduct banking transactions. With a computer system in the kitchen, one could "program" the oven and stove, leave the house, and find the meal ready to serve on returning. Some of these ideas were to take root in the decade of the seventies.

for critical circuits at Rockwell.



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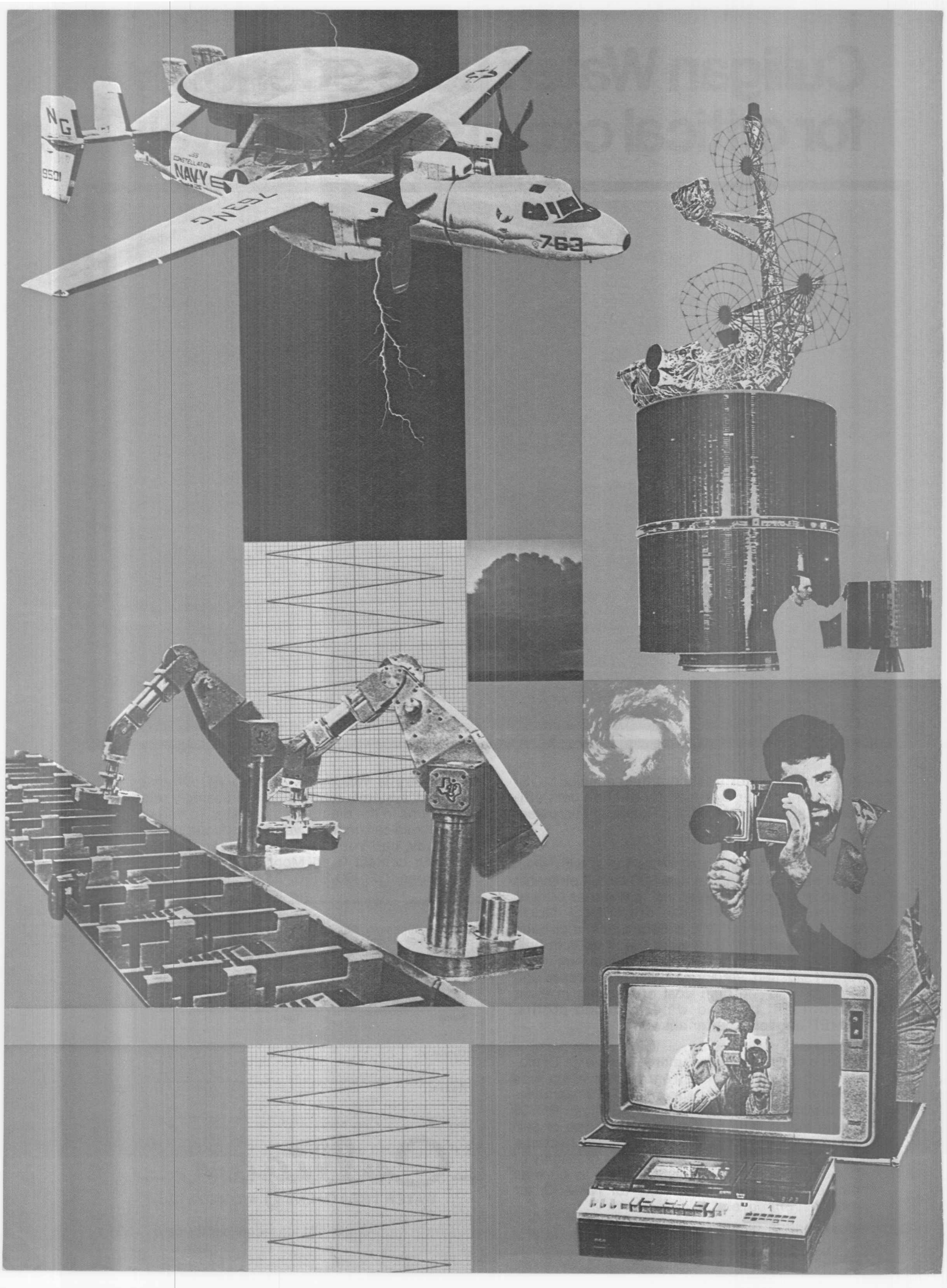
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DURING THE SEVENTIES, TWO MAJOR EVENTS CONVERGED TO LEAVE THE WORLD FOREVER ALTERED: THE END OF CHEAP ENERGY AND THE BIRTH OF THE MICROCOMPUTER. THE FIRST MEANT IMMEDIATE ECONOMIC UNCERTAINTY AND A SERIOUS CHALLENGE TO THE PRODUCTIVE MIGHT OF THE WEST. THE SECOND WAS THE START OF A DIGITAL REVOLUTION THAT SHOULD ULTIMATELY INCREASE HUMANITY'S CONTROL OF THE WORLD IT INHABITS. ALREADY DIGITAL ELECTRONICS IS EXTENDING THE RANGE OF HUMAN COMMUNICATIONS, THE SCOPE OF THE HUMAN INTELLECT, AND THE VARIETY OF GAMES PEOPLE CAN PLAY.

Chapter 8

Put the 1970s on an analyst's couch, and the diagnosis might well be mixed neuroses. There were years of tension and unwinding. Years of progression and regression. Years of plenty and famine. Aside from war, the big fears were rooted in energy scarcities and inflation. In electronics the integrated circuit was king, and from the look of things, it was going to be a long reign indeed.

Powerful digital computers shrunk midway through the seventies to fit on a tiny chip of silicon smaller than a fingernail. More important even than size, however, was the fact that integrated-circuit computer power was now becoming so cheap that equipment designers in every field had to consider adding it to their products.

Chip-sized microprocessors and microcomputers, and their allied components, were turning up everywhere. Microwave ovens, color TV sets, burglar alarms, toys, stereo systems, electronic organs, food processors, air conditioners, thermostats, and furnace controls, as well as calculators and home computers, were being designed with the new IC elements. So were telephone systems and word-processing and data-processing systems for the office, to say nothing of systems for managing heating and cooling that helped an entire office building operate more efficiently.

The new ICs and their ancillary devices were being used in automobiles, medical diagnostic equipment, prostheses, and surgical aids; at supermarket checkout stands and in gasoline pumps and pleasure boats.

But the activity was accompanied by economic unease. The decade had been born in a recession that ended in 1971. Then, in 1974–75, there was another, more severe, recession as cheap energy ran out.

Starting in late 1973, the Organization of Petroleum Exporting Countries squeezed the supply of crude oil and jacked up prices notch after notch. From $2.25 a barrel for crude sold to the United States in 1970, prices shot to $30 by the end of the decade, with oil sold on the so-called spot market at $40 a barrel and up.

Economic growth slowed as countries spent disproportionate amounts of national wealth on energy. Hundreds of billions of dollars flowed to a handful of developing nations controlling the oil in the Mideast. The New York Times compared 1973 to 1929 and called it "one of the economic turning points of the 20th Century."

The increasing cost of energy affected the price of everything. A pernicious inflation took hold and crept ever higher, reaching 13% in the United States by the end of the seventies. The dollar slid; the mark and yen rose; gold jumped over the moon, soaring to more than $800 an ounce on one occasion in early 1980, with speculators forecasting that the metal would hit $1,000 an ounce within a year.

Engineers suffered with each recession. "Some EEs are too proud to apply for unemployment," an official of the Institute of Electrical and Electronics Engineers said in the March 15, 1971, issue of *Electronics*. "They never appear on the rolls. Others hang out a consultant shingle, and some just take their savings and vacation until the job market improves."

The *Electronics* article pointed to "as many as 5,000 unemployed electronics engineers in the greater Boston area and up to 3,000 more pounding the streets in Southern California's Orange County" in 1971.

Besides the economic worry, many Americans argued bitterly over a war in Vietnam that seemed endless. Finally, sudden escalation of the fighting was followed just as suddenly by a peace treaty and an American pullout in April 1975. Later in the decade, nuclear power became a favorite target of protests, and this opposition reached a climax in March 1979 when a nuclear reactor accident at Three Mile Island in Pennsylvania created wide fear of a catastrophic meltdown of the reactor's radioactive core. The threat was contained, but nuclear power came in for re-evaluation around the world.

The seventies also saw President Richard M. Nixon journey to Peking in 1972 and end more than 20 years of hostility between the People's Republic of China and the United States. Then in 1974 Nixon became the first American President to resign from his office, trapped by his attempt to cover up a break-in two years earlier at the headquarters of the Democratic National Committee in its Watergate office in Washington, D. C.

Earlier, in 1973, Vice President Spiro Agnew had shocked the nation by resigning from office while under investigation for alleged extortion and bribery. Rep. Gerald R. Ford was appointed to Agnew's post, and then he succeeded Nixon as president.

Perhaps equally amazing was the journey in 1977 of Egypt's President Anwar Sadat to Jerusalem to seek peace between his country and Israel. By the end of the decade, following talks involving Sadat, Israeli Prime Minister Menachem Begin, and President Jimmy Carter at Camp David in Maryland, peace agreements were struck.

The decade closed on a note of international anxiety. All through the seventies the U. S. had pressed detente with its old cold war foe, the Soviet Union, and new ties with mainland China. Suddenly detente appeared to have died.

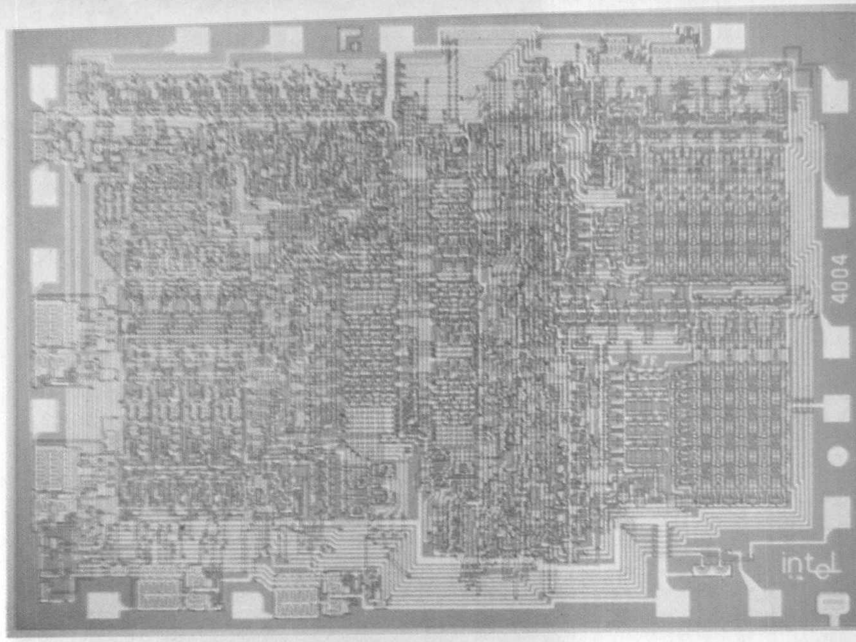
Russian troops entered Afghanistan in December 1979, and President Carter strongly denounced the Soviet Union. Cold war rhetoric was back in style, coupled with a cutting off of cultural exchanges and strategic trade with the Russians.

Through it all, electronics survived handsomely, and many new markets were created. Products that hardly existed one year caught the imagination of consumers in the next year and soon sold by the million—products like video and hand-held electronic games, hand-held calculators, digital watches, and video cassette recorders.

Along with inflation, the engineer's salary rose, too. A survey conducted by the IEEE in 1979 pegged the mean salary for its members at just over $30,000 a year for the first time, up 15% in a year and a half.

With military events at center stage in the world, President Carter called for a heavy increase in defense spending. Once again opportunities widened for U. S. engineers in this field as the decade ended.

The number of electrical and electronic engineers belonging to the IEEE climbed during the seventies, reaching 200,000 in 1979, with 160,000 in the United



The first. It began as a custom design for a Japanese calculator. When Intel unveiled it in 1971 it was the first microprocessor, the 4-bit 4004. One of a five-chip set, the silicon-gate, p-channel MOS chip measured 150 by 110 mils and was almost all random logic.

States. Moreover the IEEE was no longer merely a disseminator of technical information. It had assumed, under pressure from its U. S. members, a role in attempting to influence legislation in Congress, as well in shaping the image that the general public had of engineers and their role in society.

And there were pressures for the IEEE to do even more—for example, help limit the number of engineering graduates. The aim was to make each engineer more valuable, more likely to be used effectively on the job, and not easily turned out of work in a recession.

Computers had indeed come a long way from the days of the room-sized Eniac. The more they matured, the smaller they became. And when it appeared that they had reached the limits of smallness, they became tinier still. The seventies with their advanced ICs rocketed the microprocessor and microcomputer to prominence.

The prerequisites for such advances were in place at the turn of the seventies. Metal-oxide-semiconductor (MOS) technology was workable and improving daily. It was being used in shift registers, multiplexers, and read/write (random-access) and read-only memories (RAMs and ROMs) of modest complexity. MOS sales in 1969, including custom work, ran between $30 million and $35 million, and a market in excess of $100 million was forecast for 1970.

Desktop calculators were selling rapidly, with competitive manufacturers eagerly seeking chips to reduce the bulk and expense of their products. Over 50% of the MOS integrated circuits shipped by the U. S. in 1970 went into calculators, most of which were made in Japan.

The calculator manufacturers insisted upon customized MOS large-scale integrated circuits, but the semiconductor manufacturers pressed for standardized designs. The calculator market demanded proprietary chips. The chip makers did not want to be tied to any one buyer; they proposed partitioning the calculator architecture in an attempt to isolate circuits that might be attractive to more than one calculator maker.

From this partitioning, it was only a matter of time before the computer-on-a-chip turned up.

In August 1969 Intel Corp., then based in Mountain View, Calif., had been asked by the Busicom Corp. of Japan to design calculator ICs. Marcian E. Hoff, now credited with the development of the first microprocessor, was Intel's manager of applications research. He remembers today that Busicom's requirement was unique, in that it called for a chip set to support a family of calculators.

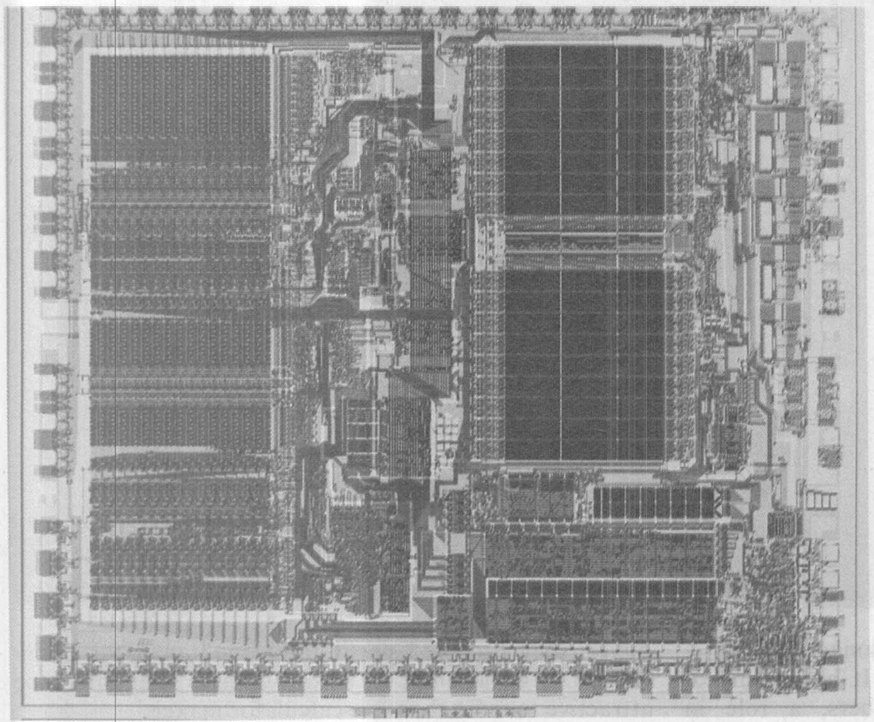
"They wanted to use ROM programming techniques to customize it," Hoff recalls, adding that "instead of making it look like a calculator with some programming capabilities, I wanted to make it look like a general-purpose computer programmed to be a calculator."

Busicom approved Intel's design in October 1969. But, says Hoff, "Intel recognized that there was a market for computers as components." In June 1971 Intel announced the 4004 microprocessor family.

The 4004 chip set was designed by Federico Faggin, now president of Zilog Inc. It comprised a 256-byte ROM, a 32-bit RAM with a 4-bit output port, a 10-bit shift register and output expander, and a 4-bit microprocessor. All had been made with p-channel silicon-gate MOS technology. The shift register measured 4,505 square mils and each of the three other units roughly 16,500 mil². The CPU could control up to 16 ROMs and 16 RAMs, for a total of 4,096 bytes of ROM and up to 4,120 bits of RAM.

Intel was not the only one to make a processor with large-scale integrated circuits. Fairchild Camera and Instrument, American Microsystems, Texas Instruments, Electronic Arrays, the Autonetics division of North American Rockwell, and Mostek all had contracts to produce calculatorlike chips and chip sets.

Meanwhile Computer Terminals Corp. (now Data-



n-channel microprocessors like Motorola's 16-bit 68000, left, with 68,000 transistors and measuring 246 by 281 mils, head for production. Its regular architecture is organized neatly into functions like microcode (two dark areas toward the top).

Like lightning. Striving for the exceptional speed needed in scientific applications was the Cray-1 vector processor, right, introduced in 1976. It could handle 80 million floating-point operations per second. Hardware was arranged in a semicircle to minimize interconnection lengths.

point Corp.) had approached Intel two months after Busicom approved what became the 4004 microprocessor. A new challenge was raised. Could Intel integrate the registers and push-down stack of an intelligent terminal that Computer Terminals had designed?

The Computer Terminals processor "was not significantly more complex than the one we had just completed defining for the calculator company," Hoff says. "So we proposed, instead of just building the registers, that they do the entire processor as a single chip."

But when the Intel design team came across an aspect of the architecture that they felt was too limited, they changed the chip. The resulting IC was not compatible with the Computer Terminals' machine architecture, and it never was used in the terminal it was intended for. Instead, Intel put it on the market as the 8008 microprocessor, and Texas Instruments designed a chip to Computer Terminals' specifications.

The 8008 was the first 8-bit microprocessor. Measuring 125 by 170 mils in an 18-pin package, it was offered in sample quantities in early 1972 for $200. The device contained an arithmetic unit, seven 8-bit data registers, and a memory stack. It used 45 instructions.

More versatile than preceding designs, the 8008 interfaced to standard memory products like the 1101 RAM, 1601 and 1701 ROMs, and the 1400 series of shift registers. Its 14-bit addressing capability enabled it to access as many as 16,384 bytes, and memory types could be positioned anywhere in its maps, as in a von Neumann machine.

By the spring of 1973 Intel was shipping microcomputer kits. In each kit, the microprocessor was supported by more than 10 times its worth in memory and peripheral circuits. Estimates were that by 1975 tens of thousands of such kits would be sold by the industry for a total market of $50 million. By 1979 the market had swelled to $331 million for microprocessors and single-chip microcomputers.

Intel, Fairchild, National Semiconductor, and Rockwell were in the running in 1973. By this time National had introduced its General-Purpose Controller/Processor, a 4-bit device that could be paralleled in bit-slice fashion for word lengths up to 32 bits. The company said that any instruction could be performed if the processor's 23-bit micro-instructions were rearranged in 100-word ROMs. Rockwell's 4-bit Parallel Processor was also microprogrammable. The processor chip used special RAMs and ROMs that could be expanded up to 24,000 words. It had a 5-microsecond cycle time and could execute 50 instructions.

But competition was heating. AMI was readying an expandable kit that could support 8-, 16-, and 32-bit word lengths. It was to have a 600-nanosecond cycle time and 120 instructions. Signetics Corp. had in the works an 8-bit processor, the Pipchip, which used encoding techniques to decrease its memory requirements. Western Digital Corp. was developing an 8-bit, n-channel design that was going to look like a 16-bit one when microprogrammed.

In March 1973 *Electronics* quoted William H. Roberts, then vice president for research and development at Western Digital, as saying: "With good logic organization, n-channel microcomputers could rival today's minicomputers." In fact, minicomputers were beginning to look more like microcomputers. In May 1973 Computer Automation unveiled the Naked Mini/LSI. It had all the capabilities of the Naked Mini computer board but at half the cost, and large-scale integration (LSI) was responsible. The new computer was based on a seven-chip, p-channel MOS CPU that consisted

of four identical processor chips and three identical control chips.

National Semiconductor was also trying to exploit LSI for the minicomputer market. It announced the IMP-16C just prior to the Computer Automation's introduction. This unit included a 16-bit microprocessor chip, a 256-word RAM, a 512-word ROM, and input/output (I/O) drivers, all on an 8½-by-11-inch board.

Microprocessors had clearly shucked off their reputation as being mere programmable calculator replacement parts. Instead, they were assuming a role as general-purpose processing units—only they were slower than minicomputers.

By mid-1973 development aids began to turn up to help engineers, and some of this equipment included software. Intel began offering packaged microcomputers containing the 4004 and 8008, called the Intellec 4 and 8, respectively. Programming packages for the Intellec 4 included assemblers and simulators. The Intellec 8 had these too, plus a text editor and a cross compiler.

The notions of in-circuit emulation and universality were also solidifying. Applied Computing Technology offered a tool for microprocessors called an assemulator; it assembled programs that emulated the chip set.

The p-channel microprocessors were, in general, considered the first generation of assemulators. N-channel technology essentially ushered in the second generation, and Intel took a commanding position with its 8080—a 40-pin, n-MOS souped-up version of the 8008 that was to become one of the most sought-after LSI devices in the history of the business.

This is also when Intel went on its crusade of upward compatibility. The address space of the 8008 had been quadrupled—the stack was moved off the chip, so it became limited only by the size of available RAM—but the 8080 had the same basic instruction set as the 8008. The n-channel, silicon-gate process gave the 8080 a 2-to-6-μs instruction cycle time for 10 times the throughput of the 8008. The 8080 was designed by Masatoshi Shima, who later left Intel to join Zilog and there designed the Z80, which had many enhancements over the 8080.

Complementary MOS was also being looked at for microprocessors, and in early 1974 RCA brought out the first C-MOS microprocessor, the 1802. Also in 1974 Texas Instruments introduced its TMS 1000, a 4-bit microcontroller that outsold all other processors—single-chip or not—by millions of units.

Motorola kept a low profile and then bowed in with flair. It introduced its 6800 microprocessor in March 1974. The device needed only one +5-volt power supply, in contrast with the 8080's three. And it had an untangled bus structure like the one the Digital Equipment Corp. put in its PDP-11 minicomputers. In addition, the new device was heavily supported. Along with the 6800, Motorola offered the Exorcisor microprocessor development system, plus four support chips: the 6810, a 128-byte, 500-ns static RAM; the 6816, a 1,024-byte ROM; the 6820, a peripheral interface adapter; and the 6850, an asynchronous communications interface adapter.

In June 1974 Rockwell beat the drums for its PPS-8. The company's earlier PPS-4, a 4-bit parallel processor, was successful, and now Rockwell doubled its word width to compete with Intel and Motorola. Built with p-channel technology, the PPS-8 offered more than 90 instructions and could directly address 16,384 bytes of ROM plus a like amount of RAM.

The first resident high-level language compiler for a microprocessor was supplied by Intel for the language called PL/M. This happened in June 1974. Late that

year Signetics began shipping samples of its 2650 8-bit parallel microprocessor, and National brought out a 16-bit device called PACE (for processing and control element). It was billed as the world's first single-chip, 16-bit microprocessor. It had four accumulators, and it emphasized interrupt control. The designers said they had chosen p-channel technology for PACE because it allowed them an instruction time of 10 μs and enabled them to fit all its components on a single chip.

By the fall of 1975 almost 40 different microprocessors crowded the market. But microprocessors were still not that easy to use.

This brought forth a barrage of peripheral and support circuits, like interface adapters and communications controllers. Eventually the chip designers took a systems approach. They studied microprocessor markets and designed the processor, peripheral circuits, and software compilers before they unleashed the device family—not as an afterthought.

Then, with shrinking die sizes, the chip makers saw that some of the peripheral functions could be integrated on the same die as the microprocessor, simplifying the interface. This is how the single-chip microcomputer was born, and it rang in a whole new spectrum of controller applications—from toys and games to engine controls.

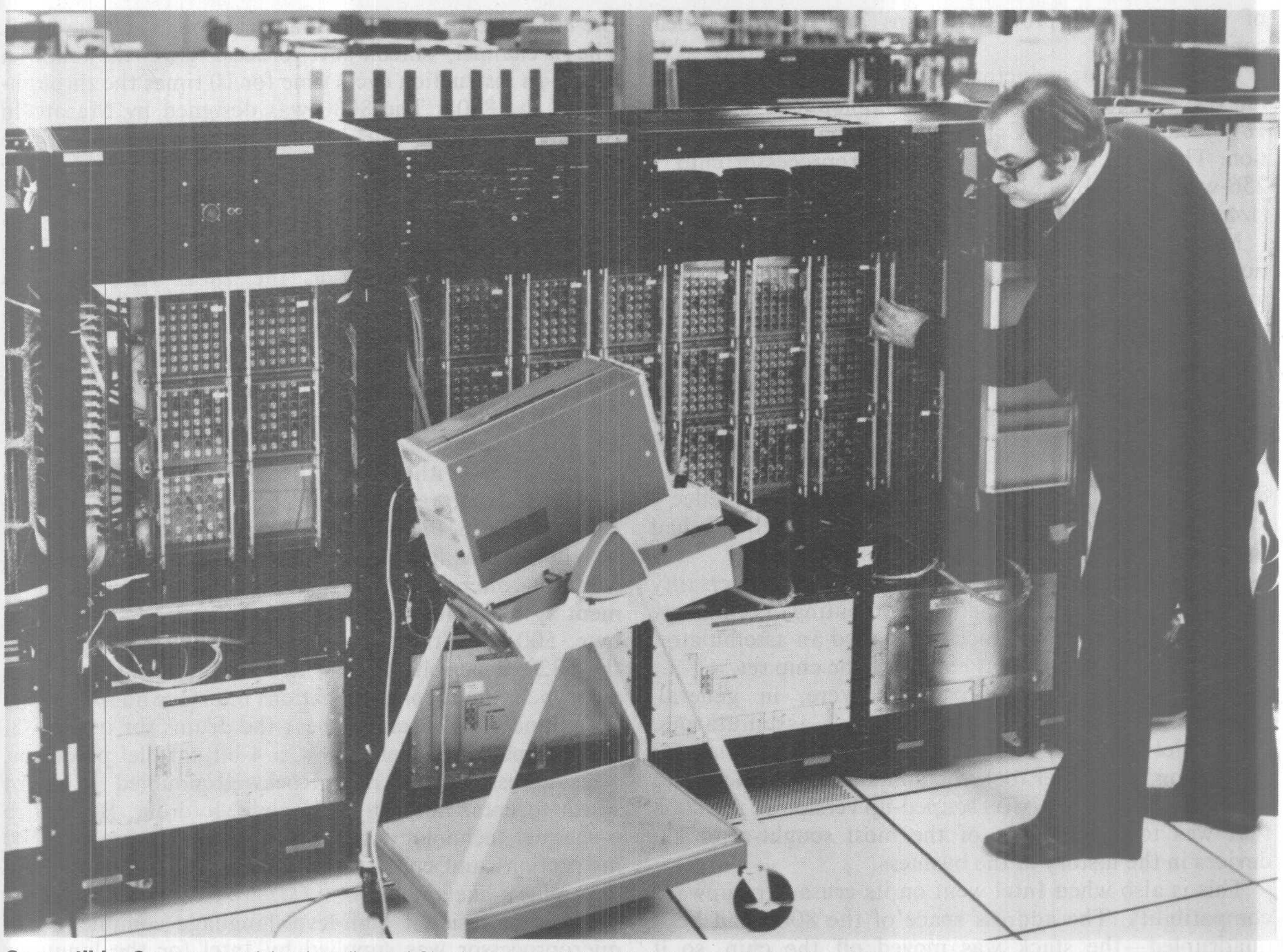
The first 8-bit single-chip microcomputer was the 8048 from Intel. But Michael Cochran and Gary Boone of Texas Instruments were awarded the basic patent, filed in 1971, for the single-chip microcomputer.

The Intel unit has CPU, RAM, ROM, and I/O. In late 1976 it was also fitted with an ultraviolet-light–erasable ROM to increase its range of application.

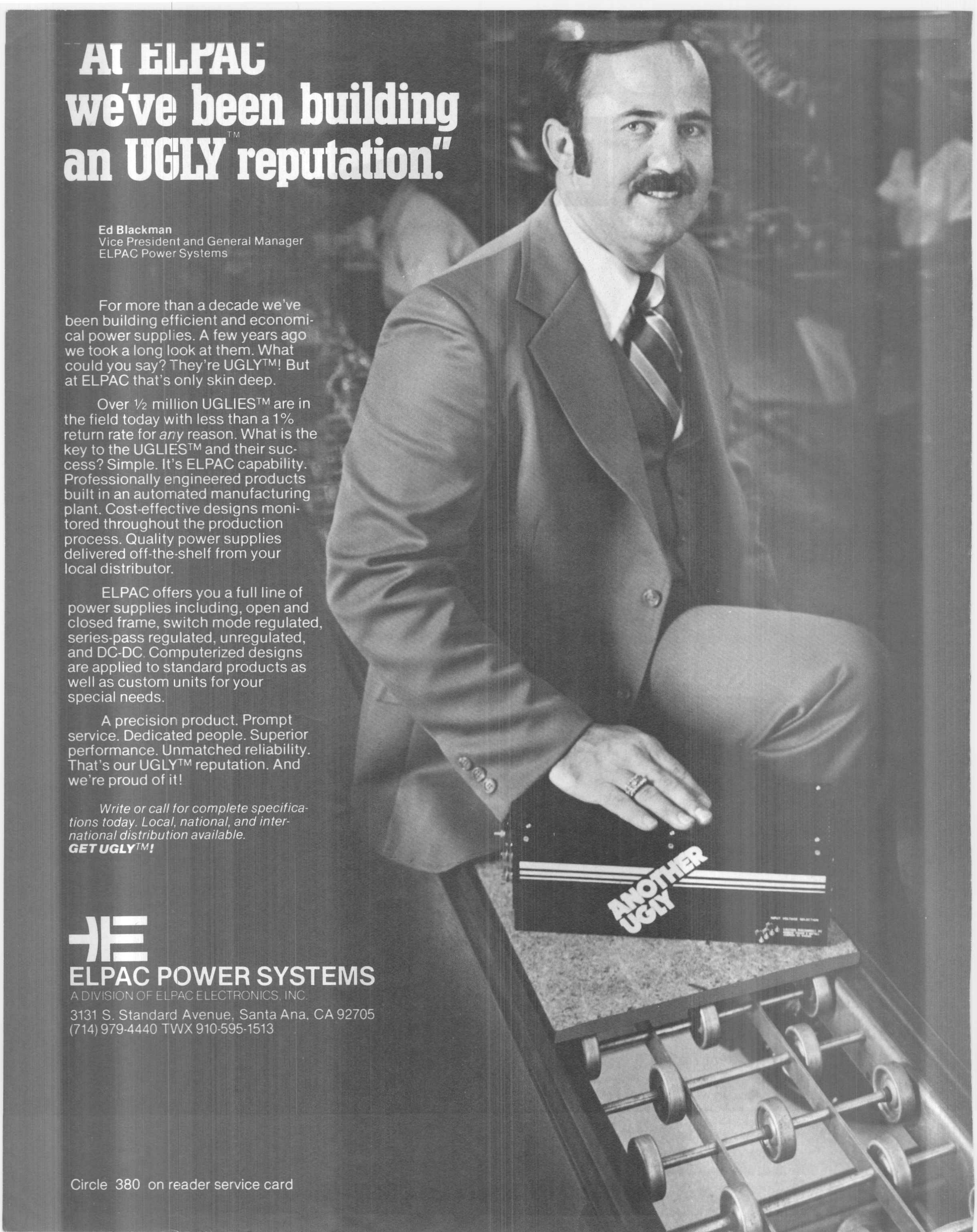
Motorola meanwhile was readying the 6802 controller, Rockwell had out samples of its two-chip PPS 8/2 controller, and Mostek had a single-chip F-8 in the wings that was to turn into the 3870 and be second-sourced by Fairchild. Microcomputers were in—not only single chips, but also single boards. LSI allowed both the chip makers and the minicomputer manufacturers to market complete, ready-to-go computers in the form of small printed-circuit modules.

The single chips became packed with functions. A good example of this came in early 1978 when Motorola announced numerous additions to its 6800 family. The 6801, offered in samples later that year, was really seven integrated circuits in one. Besides the 6800 CPU, the same substrate had the equivalent of the 6875 clock generator, the 6810 128-byte RAM, the 6830 1,024-byte ROM, the 6821 parallel I/O controller, the 6850 serial I/O controller, and the 6840 timer.

Microcomputers also were endowed with the means to make it in the analog world. In addition to all those



Compatible. Computers relying heavily on LSI, plug-compatible with but much faster than IBM System/370 models, were introduced by companies like Amdahl Corp. Here, the Amdahl 470V/6 gets checked before delivery to the University of Alberta.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internal timers and event counters, zero-crossing detectors, and even analog-to-digital and digital-to-analog converters. The 8022 from Intel, for example, had two analog inputs. The most comprehensive interfacing reached at this time (1978) was found in Intel's 2920. The microcoded architecture had analog inputs and analog outputs, allowing it to solve complex filtering equations for real-time signal processing.

Then there were the so-called hybrid machines: processors with 8-bit external buses but with 16-bit internal operations. Examples included the 6809 from Motorola, the 9980 from Texas Instruments, and the 8088 from Intel.

Single-chip microcomputers eventually were aimed at two different markets: one for moderately priced 8-bit units and another for 4-bit types with rock-bottom prices. Microcomputer makers learned that their products could not only follow on the heels of the minicomputers, but that they also had a chance to surpass the performance of the bigger machines. That started with the so-called third generation of 16-bit CPUs.

Although Intel was not the first with a 16-bit microprocessor, it was first out with a high-performance 16-bit microprocessor, the 8086. The 51,000-mil^2 chip, built with 4.5-μm, high-performance MOS technology, contained over 29,000 transistors.

The 8086 was followed by high-performance 16-bit microprocessors from Zilog (the Z8000), Motorola (the 68000), and National (the 16000). These microcomputer makers were clearly headed for yet another application area: systems. Their products would be used not only to run programs, but also to write programs for data-processing, scientific, and business applications. The new architectures were geared for the compiler writer and could execute a host of high-level languages directly.

But direct recognition of a high-level language and signal processing were not the only functions that microcomputers were designed for. More sophisticated I/O, mathematics, data encryption, and dot-matrix printer control followed. The universal controllers could accept commands from a master processor to link one of several pieces of peripheral equipment to the system bus.

Particularly important to the growth of the microprocessor was the guarantee by semiconductor manufacturers that their chips would be available from more than one source. The 8080, for example, has chalked up the longest list of second sources over the years, including Advanced Micro Devices, Texas Instruments, National Semiconductor, Signetics, Hitachi, and Nippon Electric. And Siemens is licensed to build the device.

For the big computers, the 1970s was a time of consolidation. Instead of the revolutionary changes in fundamental organization or architecture that occurred in the 1950s and 1960s, developments in the 1970s were more evolutionary. They had to be. The architecture of a computer defines how it operates and how it is to be programmed; any alterations in it force the computer user to rewrite the instructions given to the computer. Computer manufacturers were anxious to avoid making obsolete what by the middle of the 1970s was several billion dollars worth of software.

Glowing. The glow of yellow safety lights were features of the special lithography rooms, set up by every semiconductor maker, in which mask patterns were exposed on semiconductor wafers. Technicians in this American Microsystems facility are seen checking wafers.

But some change was inevitable. Continuing improvements in IC technology, reflected in the microprocessor and microcomputer, led to striking innovations in the basic logic and memory building blocks of the big computers. The ability to place more and more logic functions on a single chip forced hardware engineers to re-examine their design procedures. Some designed custom integrated circuits. Others sacrificed some flexibility to gain the reduced cost of industry-standard, such as bit-slice microprocessors. Still others compromised by using gate arrays—mass-produced chips containing hundreds of logic gates with interconnections that could be customized simply by changing the patterns of metalization deposited on them in the final stages of chip manufacture.

The composition of the industry began to change when computer companies established their own semiconductor facilities—as International Business Machines had done in the sixties—and, in turn, semiconductor companies entered the computer business.

Another dramatic hardware change was the shift to semiconductor memory. With declining semiconductor prices came compact, reliable, and inexpensive storage elements for increasingly large main memories.

The combination of semiconductor memory and new logic devices also increased the use of microprogramming in computer design. Instead of hardwiring logic gates to perform a set function, a set of so-called microinstructions could dynamically reconfigure the interconnections between the computer's logic elements. At first these instructions were placed in read-only memories, but later they were stored in random-access memory, so they themselves could be changed easily.

A major beneficiary of all the new advances was data

Electron-beam. An electron-beam exposure system, or EBES, was developed by Bell Laboratories and licensed to outside manufacturers. Here a technician holds a mask for LSI circuits before inserting it into such a machine at Western Electric's Allentown, Pa., works.

communications. With microprocessors, modems became "smart" enough to perform a variety of line-conditioning, error-checking, and error-correcting chores to make data communications faster and more reliable. And computer manufacturers encouraged data communications with the introduction of front-end processors and special data-communications software. As a result, the remote computing concept pioneered by the time-sharing techniques of the 1960s matured during the 1970s into the possibility of dispersing the data-processing function.

The makers of IBM-compatible peripheral equipment had tough going at the beginning of the decade but bounced back to thrive. This encouraged new manufacturers, led by a former IBM designer, Gene Amdahl, to introduce entire computers compatible with IBM's.

Only five major U. S. mainframe manufacturers were left to compete with IBM: Burroughs, Univac, NCR, Control Data, and Honeywell. They tended to keep pace with IBM product developments and to stay price-performance-competitive, while at the same time using new semiconductor technology to upgrade their third-generation architectures.

At the highest end of the computer power spectrum were the large-scale supercomputers designed for high-speed scientific number crunching. Control Data was most successful here.

Texas Instruments entered the arena in 1971 with its Advanced Scientific Computer, a progressive pipelined processor, a primary application of which was geological surveying for oil. But after building several, the company discontinued making supercomputers.

More prominent was Cray Research. In 1971 an innovative designer at Control Data, Seymour Cray, left the company to form his own concern dedicated to high-speed scientific supercomputers. The result, delivered five years later, was the Cray-1, a vector processor that could perform 80 million floating-point operations per second—making it the fastest computer in the world. Cray's original hardware design was optimized for speed and physically arranged in a semicircle to minimize the length of interconnections.

At the same time minicomputers, nurtured by the new LSI circuits, experienced tremendous growth through the seventies. The range of developments stretched from single-chip products to computers that overlapped the traditional mainframes. Leading the way was the young company that had invented the minicomputer—Digital Equipment Corp. of Maynard, Mass.

Indicative of minicomputer growth was DEC's growth. At the end of fiscal 1970, the company had revenues of over \$135 million. Seven years later its revenues were almost eight times that—\$1.05 billion.

The minicomputer market attracted dozens of competitors. Among the most successful were Data General, Texas Instruments, General Automation,

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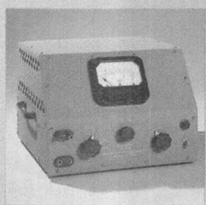

Just a few short years ago, engineers used relatively inaccurate methods of testing. Dry cells and line voltages were often used to calibrate voltmeters. Versatile standards and reliable traceability were only dreams.

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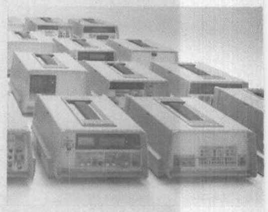
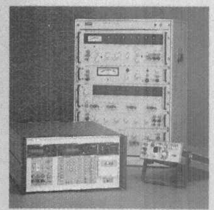
FROM MULTIMETERS TO CONTROLLERS: A BROAD LINE WITH A FIRM COMMITMENT.





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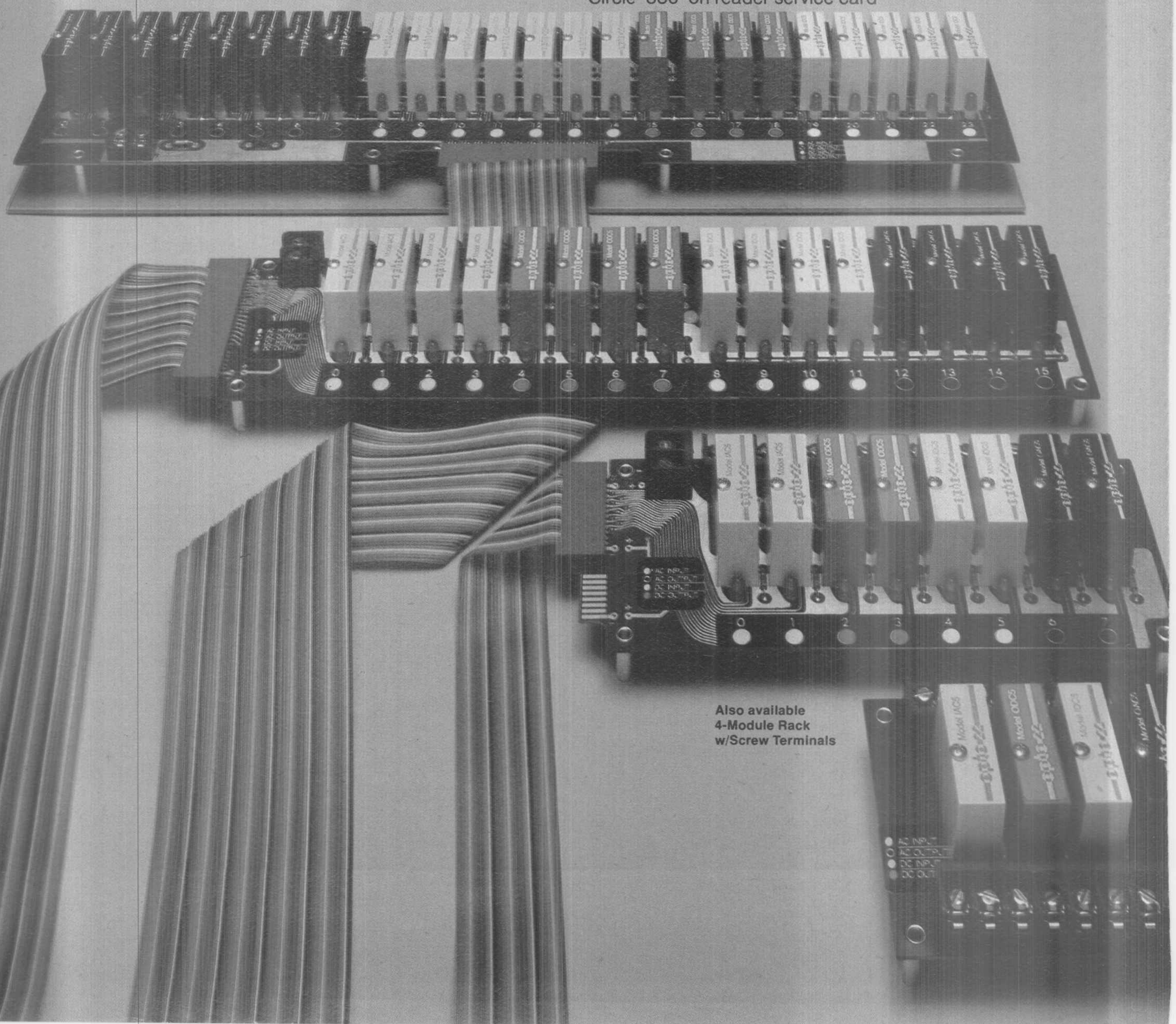


Systems Engineering Laboratories, Interdata, Tandem Computers, Prime Computer, Modular Computer Systems, Harris Computer, and Microdata.

Small businesses, in particular, became fertile ground for new computer applications and a field in which many previously discrete elements of the industry converged. Manufacturers of intelligent terminals and data-entry systems, already selling to office users, realized that the newly miniaturized semiconductors enabled their systems to become more powerful—eventually computer systems unto themselves.

Datapoint was a pioneer with its cassette-tape model 2200, introduced in 1971 and built around a microprocessor chip developed by Texas Instruments. This became the basis for a line of small-business computers that could sit on a desk top and be linked to a full complement of peripheral products. Datapoint's next unique product was the Attached Resource Computing System, unveiled in December 1977. A combination of a specialized software and an innovative coaxial cable network, it allowed users to link the company's various model processors together, so they could share peripherals, data, and the processing tasks.

One specialized office application that attracted computers was word processing. IBM, already a dominant manufacturer of electric typewriters, is credited with creating the market in 1964 when it introduced a magnetic-tape typewriter. This unit could store information on magnetic media for later modification and automatic retyping. Surprisingly it was not the traditional office equipment suppliers that jumped into the new market, but rather a host of new concerns, including CPT Corp., Daconis, Jacquard Systems, Lexitron, Linolex, NBI, Qyx, Redactron, and Vydec. They were joined by minicomputer makers like DEC, Datapoint, and Wang and by intelligent-terminal vendors like Four-Phase.

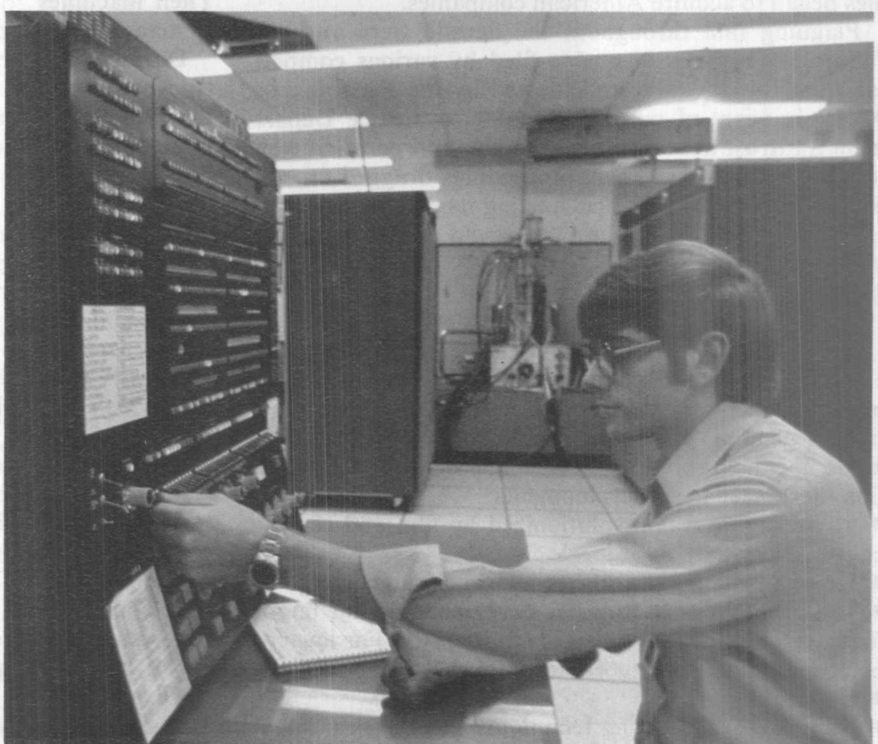
Revolutionizing the input/output process during the 1970s, and making the computer generally easier to use, were cathode-ray-tube terminals. The microprocessor brought dramatic innovations. Now it was possible to buffer both the data received by the terminal and that transmitted to the computer; hence the refreshing of the screen display could be handled in the terminal. In addition, information could be edited and verified before transmission to the computer, and this reduced errors.

Some microprocessor-based terminals became so intelligent that it was difficult to separate them from the desktop computers being sold as small-business systems. By the end of the decade almost 90 manufacturers were making CRT terminals, and more than half those on the market were microprocessor-controlled. Close to 2 million CRT terminals were installed by the end of 1979, making them the most common I/O device.

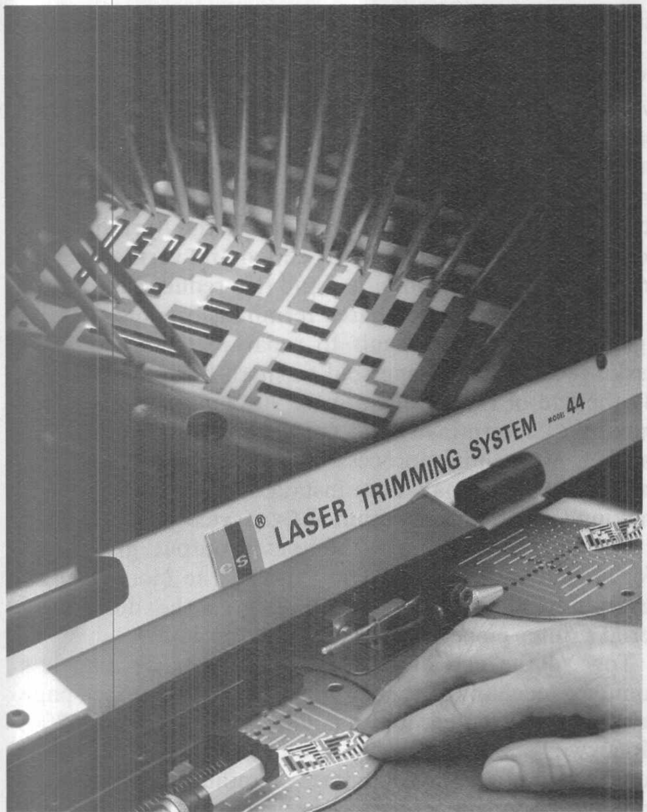
Demand for hard-copy computer output grew, too. For smaller computer systems, one of the more popular printing techniques of the 1970s was the dot-matrix serial printer pioneered by Centronics in 1970.

Toward the end of the decade printers became less complex mechanically. The high-speed nonimpact page printer was invented, and machines such as IBM's 3800, Honeywell's Page Printing System, and Xerox's 9700 could print up to 20,000 lines a minute. In addition, smaller nonimpact printers were perfected, such as IBM's 6670, the Wang Intelligent Copier, and similar units from Japanese manufacturers. And ink-jet printers became more efficient.

Even though the U. S. computer industry had been forced to consolidate, it maintained its dominance in the world market. As a result, many foreign countries either continued or expanded their protection of their domestic



Homemade. IBM developed the electron-beam exposure system that its Data Systems division was using in 1978 to expose interconnection lines on bipolar chips for its System/38 small-business computer. Each chip has 704 logic circuits and measures 4.6 millimeters square.



Trimmer. Computer-controlled laser trimmers boosted microcircuit yield by precisely removing excess thin- or thick-film resistive materials. A Q-switched YAG laser unit from trimmer pioneer Electro Scientific Industries is shown trimming a thick-film hybrid.

computer manufacturers. And to expand their activities into the highly profitable U. S. market, foreign companies began to acquire American companies.

Plaguing IBM throughout the decade were antitrust charges. Many lawsuits were filed by various competitors, but these were overshadowed by the Federal case. After six years of pretrial planning, a Justice Department antitrust action against the giant corporation went to trial in 1975. The court proceedings dragged on, and by April 1978 IBM was just starting its defense. Industry experts were expecting the 11-year-old case to last for at least another few years.

Ever larger-scale integration exerted tremendous influence on techniques for processing ICs and hybrid circuitry, as well as on interconnection in general. As in the 1960s, great advances were made in lithography for increasingly dense ICs. In addition there were these developments:

- IC packaging was revolutionized by film and ceramic chip-carriers.
- Large all-digital, multilayer hybrid circuits emerged.
- The printed-circuit industry developed fine-line boards for speed and four-layer boards for density. For low-cost pc boards, thick-film hybrid techniques were applied.
- Connectors shrunk.
- New automatic wiring techniques emerged as higher-density alternatives to the popular wire-wrap.
- Data-conversion products gradually evolved from modular to hybrid to monolithic form.

Integrated circuits of the early 1970s had circuit geometries with 20-micrometer line widths. By the mid-1970s these dimensions had shrunk to 10 μm. As the decade ended, 3-to-4-μm details were quite common in production ICs, and prototypes with 1-to-2-μm line widths were readily producible.

As the decade started, practically all IC patterns were exposed to ultraviolet light through masks either in contact with or in close proximity to resist-covered wafers. This system had satisfactory resolution but was hard on masks and also had a low wafer yield.

To overcome these deficiencies, Perkin-Elmer Corp. developed its Micralign optical projection printer in 1973. This noncontact system proved to be an outstanding success at raising IC yield and lengthening mask life. Micralign was a 1:1 optical projection system capable of exposing the entire wafer at one time, with lines and spaces 2 μm wide and an alignment error of ± 1 μm—more than adequate for ICs of the 1970s. It was perhaps the dominant lithography machine of the decade.

Electron-beam lithography was the key to making the the masks for the optical lithography units. Without its ability to make masks with micrometer-wide lines, no LSI lithography technique based on the use of either masks or reticles would have been possible.

One of the first electron-beam systems came from Bell Laboratories in 1974. Called the Electron-Beam Exposure System, it made masks by using a raster-scanned beam aimed at a continuously moving table. Wafer alignment with the beam was controlled by a laser interferometer. Both ETEC Corp. of Hayward, Calif., and the Extrion division of Varian in Gloucester, Mass., were licensed by Bell to develop commercial versions. Their machines gradually became mask-making tools at IC manufacturing plants in the U. S. and abroad.

During this time some of the more sophisticated electron-beam machines were built in house at companies like Hughes, IBM, and Texas Instruments. In fact, in the late 1970s IBM was one of the few companies to write directly on batches of production wafers, eliminating the masking step in its EL1 raster-scanning system.

A third lithographic milestone was reached in 1977 when the Burlington, Mass., division of GCA Corp. announced its Mann 4800 direct-step-on-wafer machine that could expose 1.5-μm lines at a rate of 30 to 60 wafers per hour.

Heavily researched in the 1970s was X-ray lithography, which resembles contact and proximity lithography, but with an X-ray rather than ultraviolet source. X-ray lithography's big advantages were its simplicity and high resolution and throughput. From 1975 on, Bell Laboratories, Hughes Research, General Instrument, the Lincoln Laboratory at the Massachusetts Institute of Technology, and Texas Instruments all had extensive efforts in this field. The first commercial X-ray lithography system appeared in 1978. It was developed jointly in Japan by the Nippon Telephone and Telegraph Public Corp. and Nikon.

The IC packages early in the decade were mainly dual in-line packages of 14 to 16 leads in plastic and ceramic,

effort required ever larger pinouts. By then 40-, 64-, and 68-pin packages were common.

They included large DIPs, smaller quad in-line packages (rectangular packages with four rows of leads staggered on 50-mil centers), and still smaller ceramic, plastic, and film chip-carriers.

A popular IC package was the ceramic chip-carrier. About one third the size of a comparable DIP, it originated in 1971 at the 3M Co. in St. Paul, Minn. It was a square, multilayered ceramic package whose bottom periphery contained a pattern of gold bumps on 40- or 50-mil centers. The chip was bonded to a gold base pad inside a cavity within the ceramic. The small hermetically sealed package could be easily attached or removed from pc boards and hybrids.

The new, mostly digital LSI chips soon were affecting the hybrid microcircuit field. The extremely dense interconnection patterns required for LSI packages could be achieved only with multilayered ceramic hybrids. Thick-film hybrids were developed with as many as 15 conductive layers on a 2-by-2-inch substrate. Densities ranged from 15 to 20 chips per square inch. To this day, this density can be achieved only with this method.

Multilayer thick-film hybrids were preferred to thin films, which were harder to fabricate. Thin films, although not completely pushed out of circuit work, were used mainly for precision resistors and resistor networks.

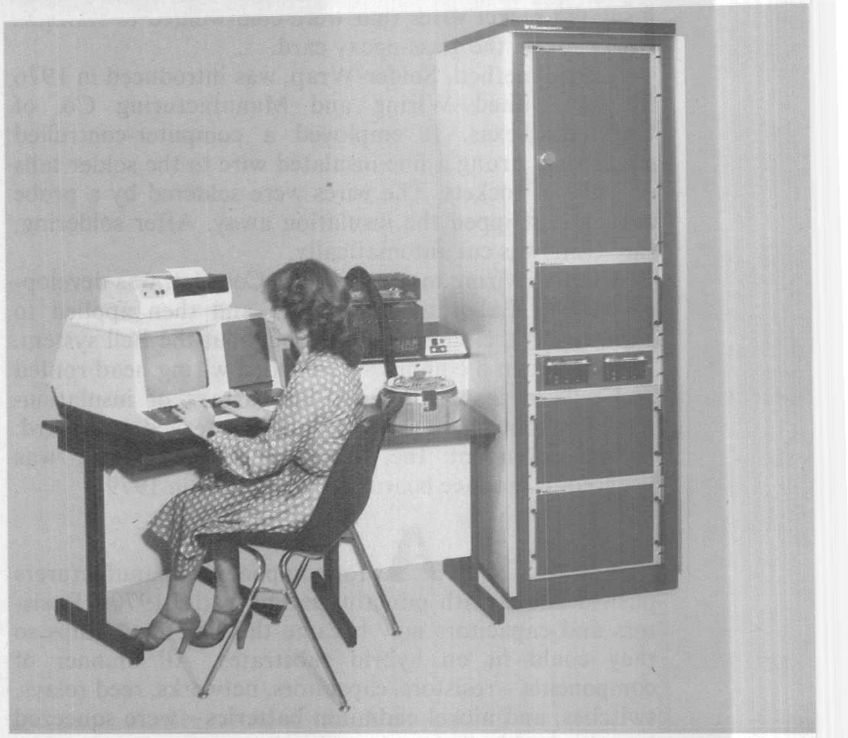
Printed circuitry also underwent change in the 1970s. The advances included the creation of fine-line boards, mass molding for multilayer boards, the use of thick-film techniques for simplified pc manufacture, and the use of porcelain-coated steel as a substrate.

As for low-cost pc boards, there were two major advances. The major suppliers of thick-film inks all developed low-cost polymers that could be screened and fired onto standard board substrates. The inks would form conductors, resistors, and insulating crossovers. The method was applied to consumer electronics, especially in Japan and Europe.

Another significant development was the use of cheap but strong porcelainized steel substrates with modified thick-film materials for the circuitry. Early in the 1970s General Electric and GTE/Sylvania screened thick-film conductors onto small porcelain-on-steel boards used in flash-bulb arrays for low-cost cameras. By the late 1970s manufacturers like the Erie Ceramic Arts Co. in Erie Pa., Alpha Metals Inc. in Jersey City, N. J., and General Electric's Lamp Department in Cleveland all produced electronic-grade (low-ion-content) porcelain on steel.

In the early 1970s the main automatic wiring methods for pc boards were Wire-Wrap and Multiwire, with some aerospace work using Stitch Wiring, in which insulated nickel wires were cold-welded to an array of stainless steel pins force-fitted into a glass-epoxy board. As the decade moved along, fast IC logic and high-density interconnects called for shorter wiring paths. Multiwire that embedded the wire in adhesive atop the board was one solution.

Another was Planar Stitch Wiring, announced by Accra Point Arrays Co. of Santa Ana, Calif., in 1973;



Tester. As new high-speed processes spawned memories with cycle times pushing 40 ns, ever faster testers were needed. Macrodata in 1979 first introduced a 25-MHz test system, the M-1, shown with its programming terminal, test fixture, and computer rack.

Attractive. Low-power liquid-crystal displays found their way into devices other than watches. Here they are being applied to one of the first hand-held digital multimeters to be commercially successful, John Fluke Manufacturing's model 8020, introduced in 1977.

instead of joining wires to stainless steel pins, it used insulated nickel wires that were cold-welded to stainless steel pads on the glass-epoxy card.

A third method, Solder-Wrap, was introduced in 1976 by the United Wiring and Manufacturing Co. of Garland, Texas. It employed a computer-controlled stylus that strung a fine insulated wire to the solder tails or leads of sockets. The wires were soldered by a probe that heat-stripped the insulation away. After soldering, the string was cut automatically.

A fourth wiring method, Quick-Connect, was developed at Bell Laboratories in 1975 and then applied to Schottky TTL circuit boards throughout the Bell system. In this system a computer-controlled wiring head routed and pushed insulated wires into arrays of insulation-piercing contacts on a regularly patterned pc board. Robinson-Nugent Inc. in New Albany, Ind., was licensed to produce boards and hardware in 1979.

As for components, manufacturers pushed ahead with miniaturization in the 1970s. Resistors and capacitors now became the size of IC chips so they could fit on hybrid substrates. All manner of components—resistors, capacitors, networks, reed relays, switches, and nickel cadmium batteries—were squeezed into the dual in-line package (DIP).

Connector technology also had developments that profoundly affected interconnections. Among these were the creation of the first fiber-optic connectors, the first zero-insertion-force (ZIF) connectors, and the use of tin-lead in gas-tight high-pressure connectors.

Fiber-optic communication was one of the great advances of the 1970s. But the technique was held back until 1975 when both the Amphenol Rf division and the ITT Cannon Electric division began to market fiber-optic connectors. Engineers now had the hardware to terminate optical cable and link it to equipment or even other cables.

ZIF connectors, like so many other developments, flowed from the interlinked requirements of LSI and high interconnection density. In 1971 it had become increasingly difficult to mate multipinned ICs to their sockets without damaging the leads of a large DIP. What was needed was a connector with easy entry for the DIP and the ability to lock the DIP to the socket.

One of the earliest ZIF devices to appear was a DIP socket from Textool Products in Irving, Texas, in July 1971. By the late seventies this technique was being adapted to pc-card edge connectors, with many variations of locking actuators.

The rising price of gold was a troublesome problem for connector manufacturers, who employed this precious metal as a contact material. In 1968 Burndy Corp. of Norwalk, Conn., developed a solution. This was a gas-tight, high-pressure interconnection system. The spring force behind a sharply pointed tip caused contact material to flow, or extrude. The contact was composed of a copper alloy base plated with a tin alloy. The contact flow broke down all tarnish and corrosion, resulting in a gas-tight metal-to-metal junction. By the late seventies the company had successfully applied this principle to all sorts of connectors for all sorts of applications.

A significant development took place in the data-conversion field—the ultimate shrinking of complete systems to monolithic chips. In 1970–71 most digital-to-analog and analog-to-digital converters were large potted modules that used discrete devices and ICs on small pc boards. A sampling of thick- and thin-film hybrid converters was available, along with one lonely monolithic 8-bit d-a converter from Precision Monolithics Inc. of Santa Clara. Calif.

By 1975 the emphasis had shifted from potted modules to hybrid converters. In that year module makers like Datel, Burr-Brown, and Analog Devices came out with hybrid converters, as did National Semiconductor. Later, many module companies opened monolithic facilities. By the decade's end hybrids and monolithics had almost pushed modular converters out of the picture.

The soaring application of linear and digital IC technology shaped instrument design throughout the decade. And the advent of the microprocessor created such shock waves that the full impact had not been felt by the end of the seventies.

There were complaints about the ability of automated test equipment to keep up with the changes in IC design. One solution was offered by Membrain Ltd. of Britain (later absorbed by Schlumberger). Membrain's first product was a functional pc board tester in 1971 that could be expanded to 1,000 pins from a basic 20-pin unit.

Macrodata, another new company, had introduced its first tester, the MD-200 in 1970. It was the first MOS LSI tester to function at 2 MHz, and it placed the pin electronics in the test head, a design that decreased noise and is the major technique in use today. Throughout the decade Macrodata put out state-of-the-art systems, including the first 25-MHz memory test system, the M-1, in 1979.

Another newcomer in 1971 was Trendar (acquired by the John Fluke Manufacturing Co. in 1973). Trendar had the model 2000, which used a new coding scheme—an early form of signature analysis called transition counting—to compare a known good board with a test board.

Faultfinders Inc. and Testline (now part of Fairchild) were also founded during this period and, along with Zehntel Inc., pioneered the in-circuit philosophy for board testing. These testers checked the location and function of components by isolating each device.

Established instrument companies also entered the automated testing business. Schlumberger Ltd., the French oil equipment and electronics conglomerate, introduced a test system, as did Fluke. A highly versatile system, the 4500, was offered by E-H Research Laboratories of Oakland, Calif. Built around an IBM 1130, the tester could function at speeds of up to 1 GHz in a 40-pin configuration. The technology to build the 4500 boosted its price to as much as $750,000, which few customers cared to pay for a capability that would not be needed for years. In a more down-to-earth vein, Tektronix

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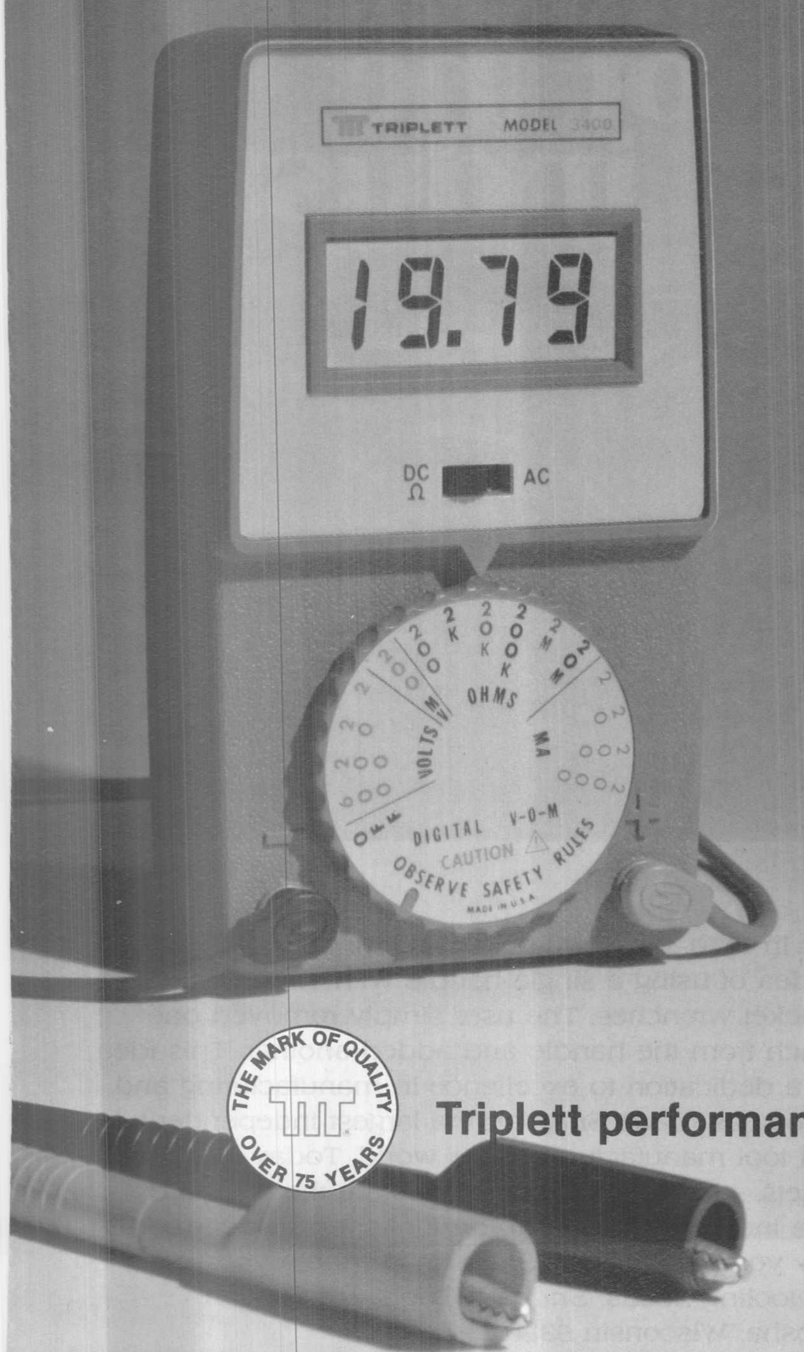

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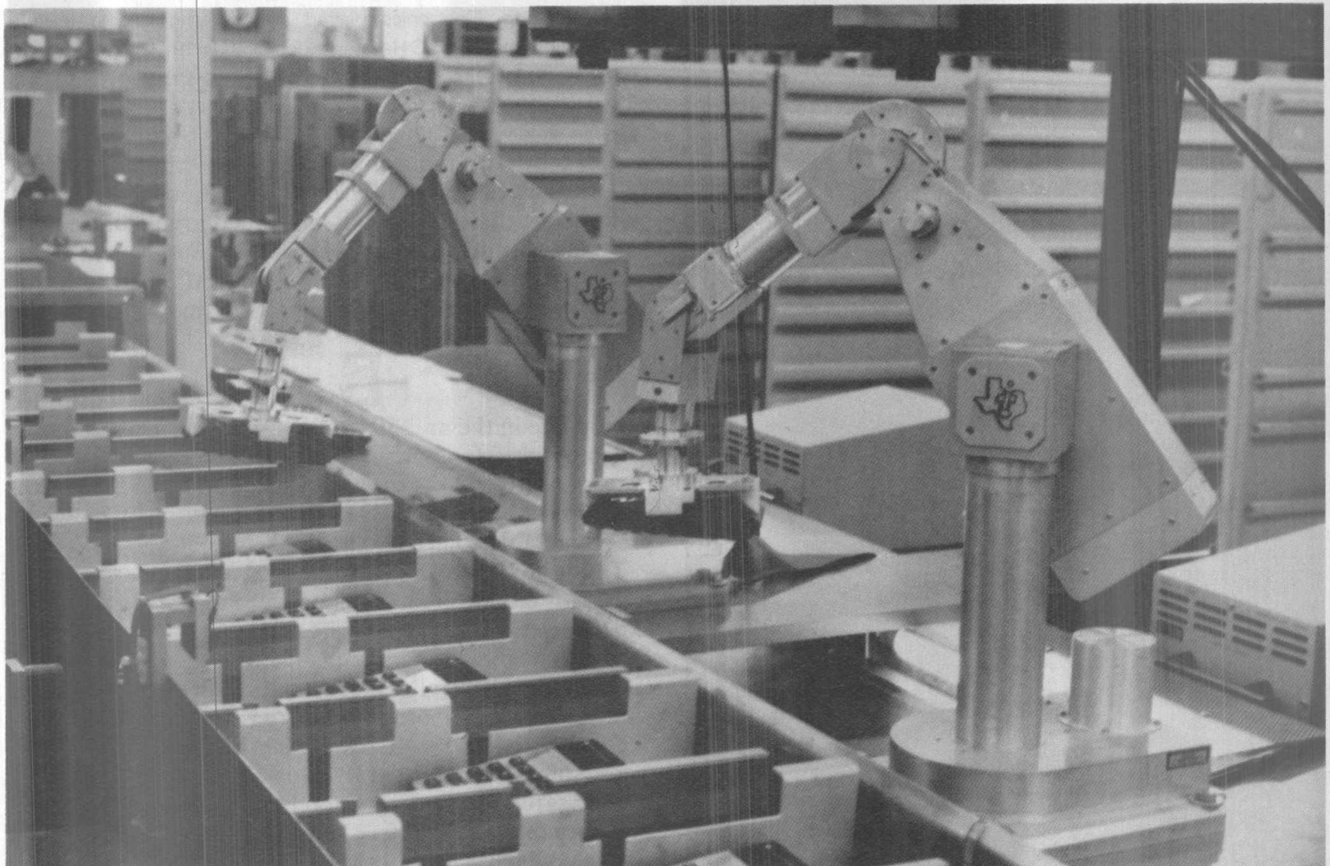


Pick and place. Robot arms made some progress during the decade in taking over boring and dangerous jobs. These at a Midland, Texas, plant of Texas Instruments transfer calculators from one conveyor belt to another. Overhead TV cameras help them search for "targets."

marketed the S-3160, a general-purpose LSI tester that worked at speeds up to 20 MHz.

Companies already in the automated test business expanded their lines. In 1970 the Fairchild Semiconductor Test division introduced its Sentry LSI tester, the model 400. The unit was designed to be modular, expandable as testing requirements grew. Teradyne and GenRad also put out IC testers.

Although programmable instrumentation had been built in the late 1960s, the task of integrating such instruments into a system was considered a designer's nightmare. To overcome the problem, Hewlett-Packard attempted in December 1971 to standardize the connectors, cabling, timing, voltage levels, and codes of its future instruments. The company came up with a bit-parallel, byte-serial communications interface, or bus, that eventually was adopted internationally. It is known by a variety of names—HP interface bus (HPIB), general-purpose interface bus (GPIB), IEEE-488, and IEC 625-1. The interface, which first appeared in HP's 3330A/B automatic frequency synthesizer, became common in instruments by the end of the decade.

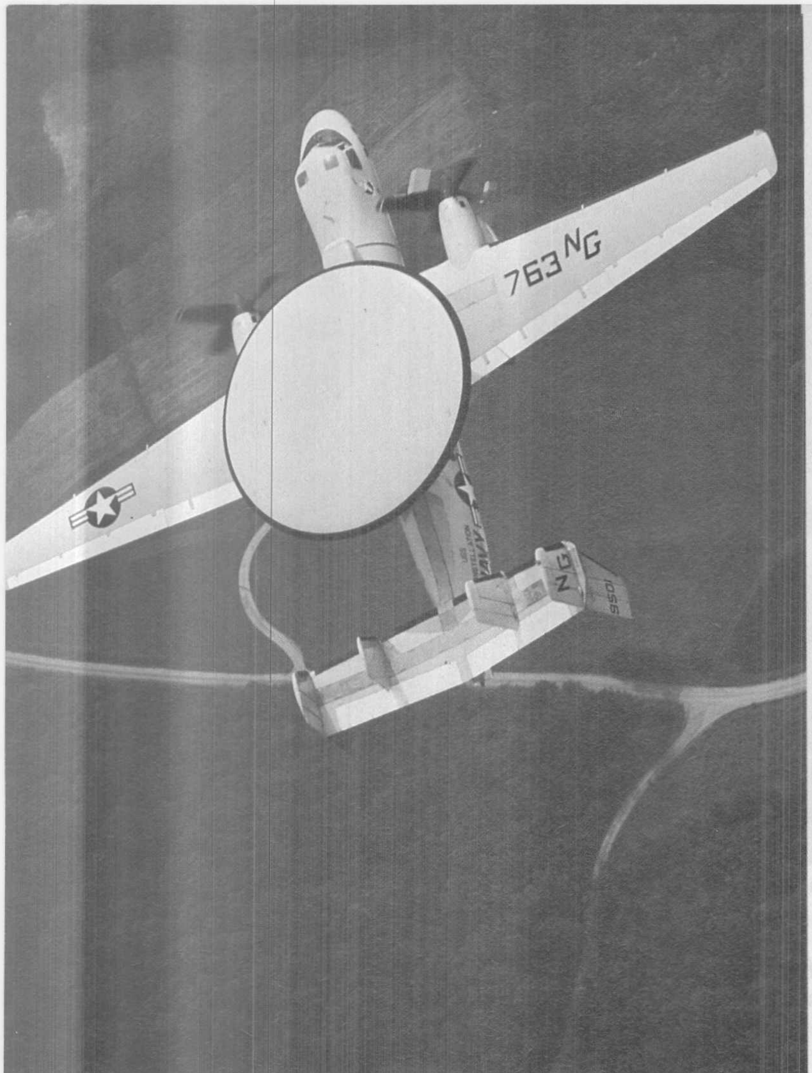
The oscilloscope competition between Hewlett-Packard and Tektronix led to the development by HP of the first complete data-domain logic analyzer, the 1601L, in 1973. The instrument, which displayed events on several channels as a series of 0s and 1s, actually resulted from an unsuccessful effort to build a digital-processing oscilloscope. That same year Biomation came out with the first time-domain logic analyzer, the 810-D. It displayed such events as square waves varying between a logic 1 level and a logic 0 level.

That such instruments were immediately popular is not surprising; the use of digital logic was becoming universal. It was evident in digital synthesizers, such as the model 5100 introduced in 1974 by Rockland Systems, and in digital multimeters, such as the 8600A and the 8800A introduced the same year by Fluke. These two DMMs, half the size of previous instruments, were designed around custom digital LSI.

But the greatest impact on instrumentation was made by the microprocessor. In 1973 Intel introduced single-board computers for use in developing programs for its single-chip computer, which the following year began to find its way into instrumentation.

The first oscilloscope to use a microprocessor was the Hewlett-Packard model 1722 in 1974, and the microprocessor was HP's own chip, the 352. Developed for the HP-35 calculator, the microprocessor computed frequency and time intervals, which could be displayed on the scope's light-emitting-diode (LED) readout.

In the same year Fairchild Systems Technology used a microprocessor in its Qualifier 901 IC tester for what was potentially one of its most important roles—performing self-test routines at system startup. The following year the first microprocessor-based synthesized signal generator and counter/timer, Fluke's 6011A and Dana Laboratory's series 9000, respectively, came on the market. Then



Early warning. Electronics played a [illegible] aircraft. Grumman's E-2C Hawkeye, deployed in 1974, uses a General Electric radar—its antenna in the circular radome—to automatically track aircraft flying low toward the U. S. Navy's fleets.

spectrum analyzers, instruments that stood to benefit most by being made easier to operate and read, incorporated microprocessors in 1977. There was the Tektronix 7L18 plug-in for the company's 7000 series; it used the microprocessor to control the setting of frequency and sweep automatically and to manage an MOS memory that stored previous traces so they could be compared to live data. And there was the HP-8586A, which contained three processors to control settings, calculate results, and compute correction factors.

Instruments to help designers build microprocessor-based systems also were developed. The first "universal" system for different microprocessors was Millennium Systems' Microsystems Analyzer in 1977. The instrument was based on one measurement technique developed by HP, signature analysis, and on another developed by Intel, in-circuit emulation.

Signature analysis, based on signal tracing, translates bit streams into hexadecimal codes, or signatures, which are then compared with the correct signatures on a circuit diagram. In-circuit emulation mimics the operation of a microprocessor by using hardware that is linked to a user's prototype system with cabling.

The universal development system was quickly adopted by Tektronix, by agreement with Millennium, and introduced as the Tektronix 8001. Another universal system, one that provided a distributed architecture, was built by Futuredata in 1978, and Futuredata then became part of GenRad. In 1979 Hewlett-Packard introduced its first universal development system: the 64000.

Even before computers shrank to chip size in the mid-1970s, industrial electronics found widening use for them. Chemical and petrochemical process control, the largest industrial electronics market, was joined by manufacturing processes in 1971 when programmable controllers made their debut.

The forte of the programmable controller was versatility. With one, a plant manager no longer had to scrap expensive relays and hard-wired logic modules each time production requirements changed. Instead he reprogrammed the controller by replacing one or two braided-wire read-only memories or read/write core memories.

During the early 1970s industrial electronics sales were spurred by Federal legislation that mandated greater safety for factory workers. Farthest reaching was the Occupational Safety and Health Act of 1970 (OSHA), which, among other things, created demand for noise-measuring instruments, like audio dosimeters. The Federal Coal Mine Health and Safety Act of 1969 produced a new market for underground safety equipment that included low-light TV cameras, gas sensors, and dust-particle detectors. Federal standards for automotive emissions and safety further broadened the need for electronics.

In 1972 *Electronics* said that automotive industry analysts were predicting that "by 1980, vehicles will contain as much as $100 worth of electronics." The predictions were on target with respect to several top-of-the-line models.

Catching on slowly were industrial robots, or automatic manipulators, boosted by robotics pioneer Unimation Inc., Danbury, Conn. Sales of minicomputers to industrial users boomed in the early 1970s. The machines quickly assumed more and more materials-handling chores—from sorting letters to moving air freight and even watching their own operation.

With the advent of microprocessors, designers of industrial equipment could buy a chip set like Intel's 4-bit MCS-4 and then design the circuit boards, systems, and packaging for themselves. This flexibility, plus the high reliability inherent in fewer ICs, allowed inexpensive microprocessors to begin replacing minicomputers and hard-wired controllers in virtually every industrial electronics application.

Microprocessors also permitted distributed control, in which a microprocessor-based controller takes charge of a local control loop, thus freeing a central computer for other duties. One of the first such systems was Honeywell's TDC (total distributed control) 2000 process-

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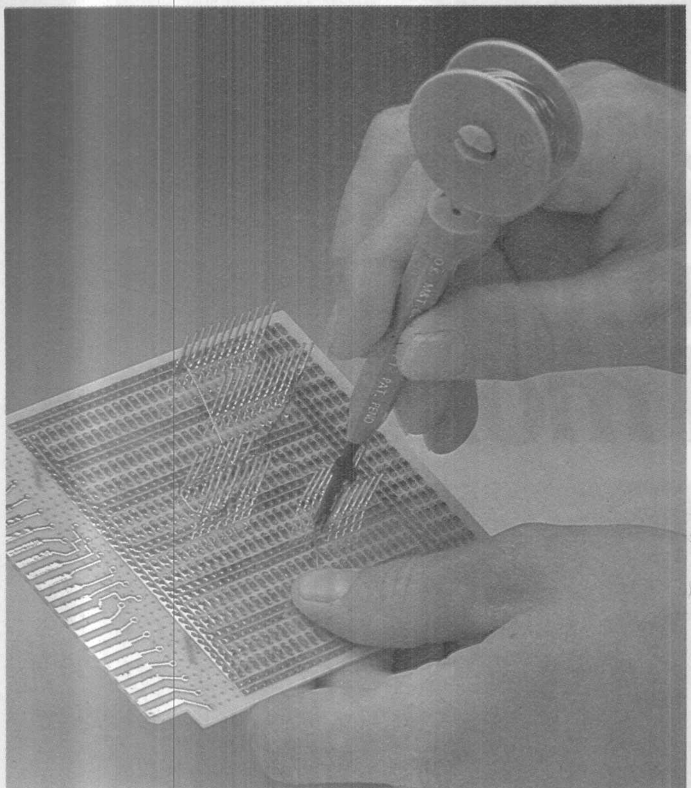
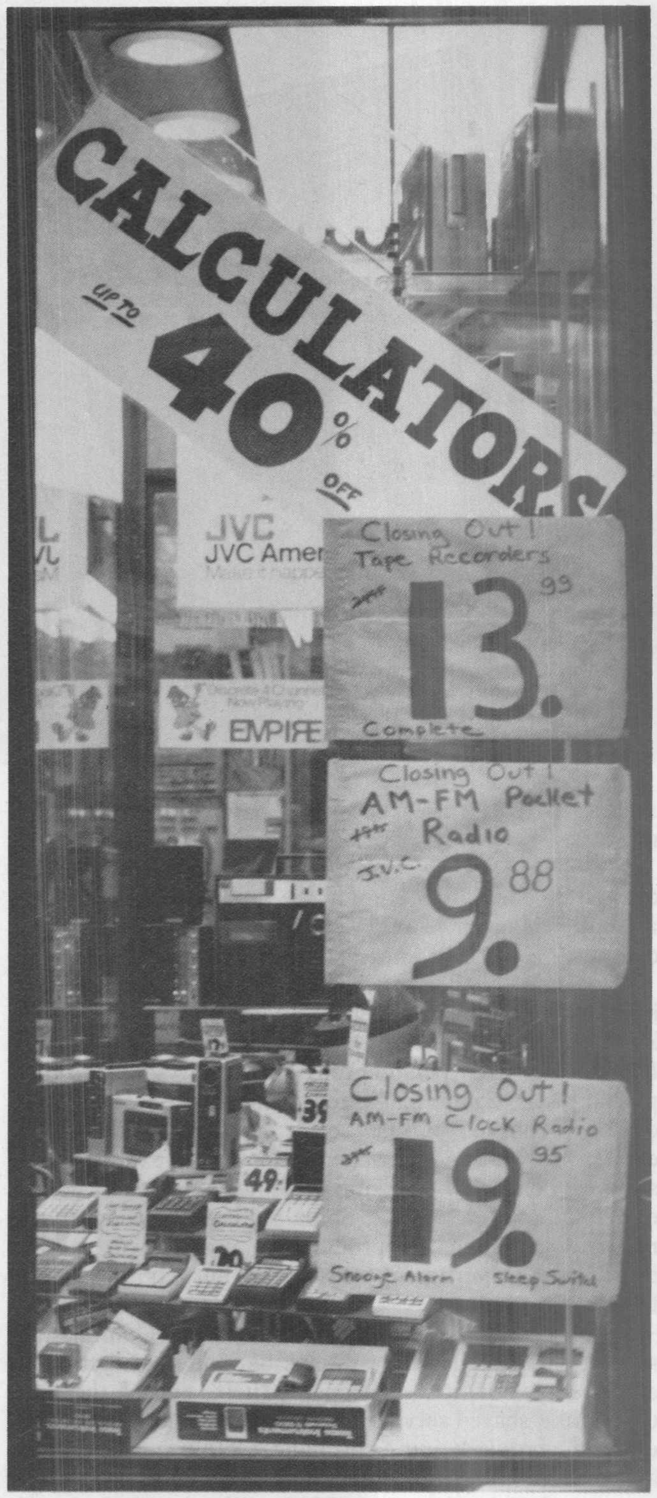



WRAPPING WIRE


AW-5T



Downward. Prices of many consumer electronics items were being drastically reduced in step with the ever higher-volume production of integrated circuits. This photo was taken in 1976 at a store in New York anxious to move its merchandise.

control system, introduced in 1975.

The late 1970s saw the creation of two new industrial electronics markets: lasers and energy-management systems. Low-power (1-to-2-milliwatt) helium-neon lasers proved reliable enough to measure, sort, and inspect components, while larger (1-to-5-kilowatt) carbon dioxide lasers proved faster than induction furnaces for heat-treating such metal parts as the teeth on chain saws. Even more powerful helium-cadmium lasers, with beams expanded to lower and safer power density, were used by the U. S. Coast Guard to monitor oil spills in 1976.

Energy management, a field pioneered by aerospace companies looking for ways to cut the heating, ventilating, and air-conditioning costs of their huge factories, became a lucrative industrial market when oil prices jumped. Tying together technologies from solar heating to load shedding under the aegis of a central computer or distributed microcomputers, energy-management systems often paid for themselves within a year by slashing fuel bills as much as 20%.

Radar went digital, too, in the 1970s. It had become deeply involved with information processing and data handling at high rates. Microprocessors and associated memories were sprinkled everywhere in the radar system.

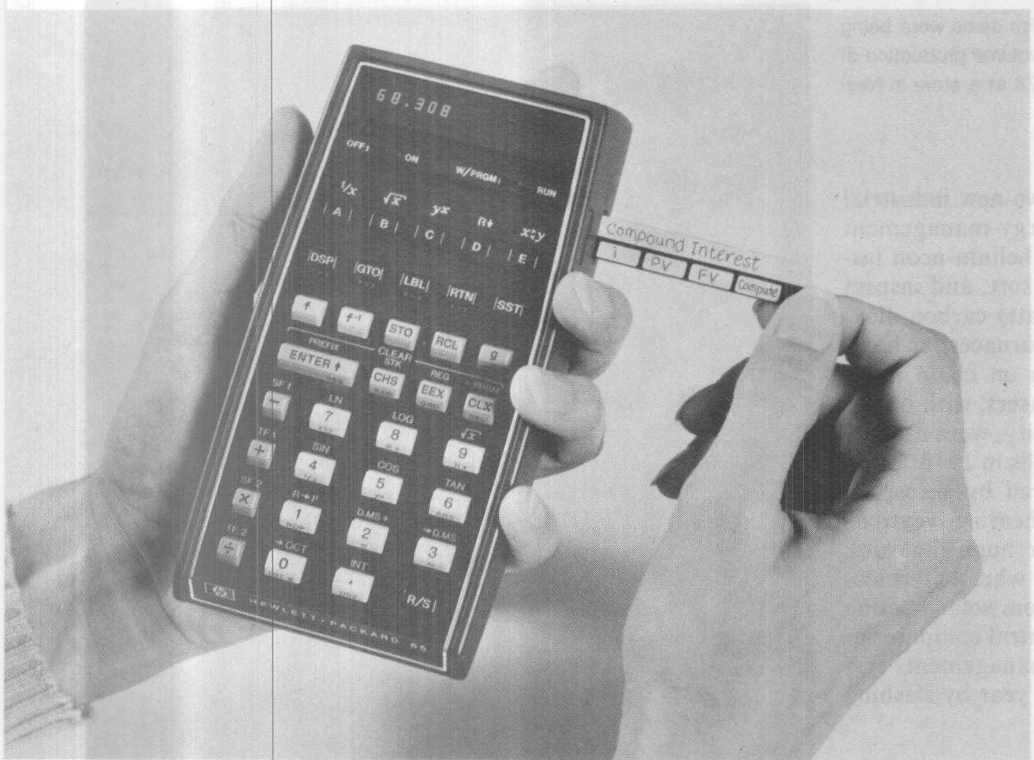
When rain or jamming interfered with signal reception in aircraft, for example, automatic adjustment of the radar threshold and other parameters could avoid false target indications. Such systems were installed in the Grumman F-16 fighter jet and the Grumman EA-6B reconnaissance aircraft.

The decade saw further experimenting with phased-array radar. The Pave Paws long-range search radar built by Raytheon Corp. and installed in Massachusetts was typical. These systems, with their electronically, rather than mechanically, steered antennas, still needed some technological breakthroughs, including cheap computer software control to steer the antenna pattern and cheaper production of phase shifters. Cheap, reliable solid-state oscillators for each element in the array were also needed. By the end of the decade, these problems had not been solved.

High-speed digital processing and low-cost microprocessors and memory made synthetic aperture radars more promising for relatively high-resolution applications. Both range and azimuth resolution of less than 10 feet soon became possible with these systems, which stored the information from multiple scans of a target. This information, in turn, was computer-processed to produce an enhanced picture. Such systems used upwards of 100 megabits of memory for satellite mapping, crash location, and flood control, among other applications. They were used, for example, on the Pioneer-Venus radar mapper, an interplanetary probe built for the National Aeronautics and Space Administration by Hughes Aircraft Co.

An experimental microwave radar receiving system front end based on an Intel 8080A processor was developed by GTE Sylvania in 1976. Intended for reconnaissance, it operated in the 0.5-to-40-GHz region of the spectrum and covered just about any frequency an enemy or friend might broadcast on.

In the civilian world, cable television, a novelty and a promise in the 1960s, took off in the seventies. It expanded from a TV subscription service to a two-way data



Smart set. Hand-held calculators became quite sophisticated. At $795 in 1974, Hewlett-Packard's HP-65 was the first such programmable unit. Programs written and edited on narrow magnetic cards could be stored and later inserted into the machine.

system, with the user becoming part of an interactive network.

The Mitre Corp. was one of the first to propose computer-aided instruction in the home as an educational tool. It suggested in 1971 a timeshared, interactive, computer-controlled information TV system.

By the end of that year, more than 15 computer-aided instruction systems were in operation in the U. S., including southern California; Reston, Va.; Overland Park, Kan.; and Washington, D. C. Fifty-nine million people in the country had access to such a system. One or a combination of three basic types of services were either provided or envisioned in these experimental systems: household (banking at home, shopping at home, electronic mail delivery, opinion polling), business (data retrieval, document reproduction, credit-card validation), and government (fire and burglar detection, fingerprint retrieval).

In 1973 the Federal Communications Commission mandated that all CATV systems be made bidirectional, and that year Mitre developed Mitrix, one of the first CATV time-shared services. It had over 131,000 subscribers in the network and could handle 8,000 subscribers at any one time. With progress like this, the CATV equipment market grew to nearly $500 million by 1976.

Two new—and volatile—consumer electronics markets were calculators and watches. In both cases prices began high and plummeted rapidly. Wide markets were created in the process.

Calculator prices that were at $395 in 1970 dropped to $200 a year later; to just below $100 in 1972; to $39 in August 1973; and to $5.99 in July 1976. The figures are for models on the low end of the performance scale. Costlier calculators with more functions were available all through the 1970s, but the low performers tended to hold down prices in general.

Another reason for lower calculator prices: "Cheaper electronic calculators come from the higher levels of MOS LSI integration and the lower cost of such chips," *Electronics* reported in March 1972. "Keyboard and display costs are also being reduced."

There were milestones in calculator manufacturing. In January 1972 Hewlett-Packard introduced the HP-35, likening it to "a fast, extremely accurate electronic slide rule with a solid-state memory similar to those in computers." The calculator, which retailed for $395, weighed 9 ounces and fit in a shirt pocket. It could perform all trigonometric and logarithmic functions, square root, addition, subtraction, multiplication, division, and several other mathematical operations at the touch of a button. The company's president, William Hewlett, predicted that the size, convenience, and power of the HP-35 would change existing patterns of calculator use. He was right. Competitive electronic "slide rules" began to flow from assembly lines.

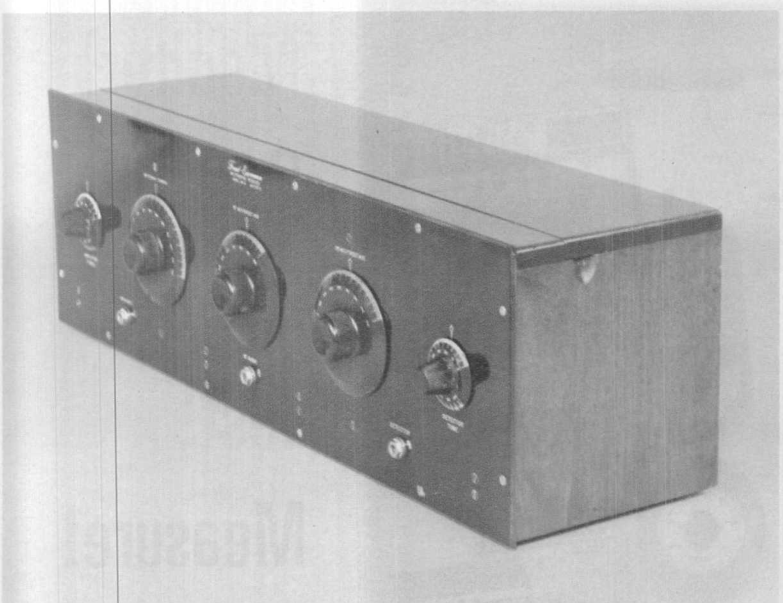
In July 1972 Texas Instruments assumed the role of a consumer products company by introducing its $149.99 hand-held calculator in test markets. TI was selling four calculators by March 1973, had set up retail distribution, and had started a development program for products other than calculators.

In August 1972 National Semiconductor's $39, six-digit, four-function calculator was ready. That year, too, Bowmar/ALI of Acton, Mass., a company that had sold its first calculators in October 1971, was reportedly the world's largest producer of the devices. It sold one model under the Sears Roebuck logo.

In February 1975 Bowmar was in bankruptcy proceedings, a victim of the industry shakeout that started in 1973. Profit margins were too slim for some

Hazeltine

Innovation in electronics from the beginning



In the early 1920's, Professor Alan Hazeltine received patents on his Neutrodyne Receiver design, which both advanced the state-of-the-art and rapidly found wide use in the manufacture of home radios. It provided a major contribution to the commercial success of radio, and innovative and practical engineering in advanced electronics technology remains a principal strength of Hazeltine Corporation.

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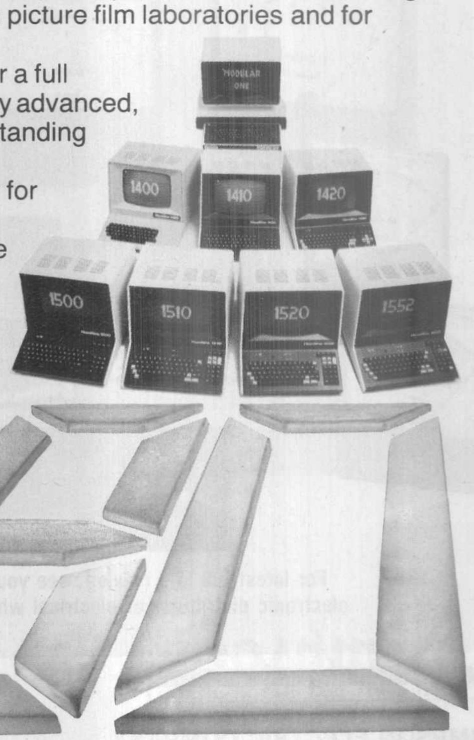

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Hazeltine **Answers for the eighties**

Stylish. The ordinary telephone changed significantly as manufacturers and operating phone companies vied to sell sets. This Flip-Phone from General Telephone & Electronics measures 2 by 2 by 7 inches when flipped closed to cover its receiver, transmitter, and push-button keypad.

companies to survive. Among the early casualties were assemblers that bought their components from aggressive semiconductor manufacturers.

One major U.S. calculator maker estimated that about 20 million units were sold in the U.S. in 1975. Domestic production amounted to only about 4 million to 5 million units. Some 6 million were Japanese, who would come to dominate the market, and the rest—almost 10 million—came from other sources.

The first electronic digital watch was introduced in the fall of 1971: the Pulsar, retailing for $2,000 with an 18-carat gold case bracelet. Touch a button and the light-emitting diodes showed the time. (It took about a year for Pulsar to add the day and date.) Not long after, the manufacturer, Time Computer, came out with a stainless steel Pulsar that retailed for $275. The company bought the chip from RCA, and one executive recalls, "We held all the original patents, were the innovators, and made a lot of money on it for a few years."

Motorola offered the first integrated electronic watch kit to manufacturers in early 1972. The C-MOS circuit, precision quartz crystal, and miniature microwatt motor sold for $15, but the company expected the price of each component to drop to $1. "Watches are going to be in the $17 range eventually," a spokesman said.

Engineers worked on liquid-crystal watch displays, trying to bring the price down and the reliability up. By 1970, low-temperature crystal materials had appeared that made LCDs practical to manufacture. By May 1974 *Electronics* was asking, "Is 1974 the year of the digital watch?" C-MOS and display suppliers, forecasting sales of 1.5 million units, thought it was, but watch companies were less enthusiastic. The watch companies conceded that semiconductor manufacturers could build watches, but they argued that these manufacturers did not understand styling and also that they did not have jewelry distribution outlets.

In fall 1974 National Semiconductor's Novus Consumer Products division introduced six watches ($125 and $220 at retail) and three electronic clocks ($34.95 and $60). American Microsystems came out with a redesigned digital-watch module that was smaller and used almost half the power of earlier modules. By February 1975 about 40 companies were offering electronic watches with digital displays.

John M. Bergey, president of Time Computer, in a December 1975 interview with *Electronics,* said: "All the figures we see suggest that there are now some 45 manufacturers and from 70 to 80 nonmanufacturing marketers of digital watches. I believe we'll see this shrink to half that by this time next year. My long-term view is that by 1980, some 20% to 30% of all watches

Replays. Video cassette recorders made a hit in the late 1970s. This SelectaVision VCT 400 from RCA, foreground, can be programmed to record up to four TV programs on different channels over seven days. It can be used to tape home TV productions.

sold worldwide will be solid-state digital models."

Hastening the shakeout was Texas Instruments' plastic-cased, five-function LED watch that sold for $19.95. The watch, introduced at the January 1976 Consumer Electronics Show, caused National Semiconductor to reduce its prices in mid-show. Six months later watchmakers were predicting a $9.95 digital watch would be on the market by Christmas.

As LCD prices dropped, manufacturers used fewer and fewer LEDs. TI introduced a watch with liquid-crystal hands in August 1976. The engineers had to connect 120 separate elements to form the moving hands; the watch retailed for $275 to $325, depending on its case.

Electronic games entered a new age when Magnavox put out Odyssey in late 1972. An interactive game designed to be played on the screen of the home TV set, it consisted of a master control box, two hand controls, an rf feed line, an antenna switch box, and frosted Mylar TV-set overlays. Odyssey retailed for $100.

A year and a half later the first coin-operated color game, Wimbledon, was marketed. Nutting Associates Inc. of Mountain View, Calif., used a transistor-transistor-logic (TTL) processor and television set to simulate a tennis match—complete with the sounds of play, a grass-green field, white border lines, white ball, tennis rackets in four different colors, and scores displayed on a bright yellow background.

By June 1974 Atari Inc. had been founded and 20 or so companies were manufacturing coin-operated electronic video games. When that market's growth slowed, it was a natural move into the consumer business. At the end of 1975 General Instrument was offering a chip for $5 or $6 that could operate six different games. National Semiconductor was offering a game for $75, and Magnavox's Odyssey 200, costing $79, had on-screen boundaries for tennis, hockey, and Smash, a combination

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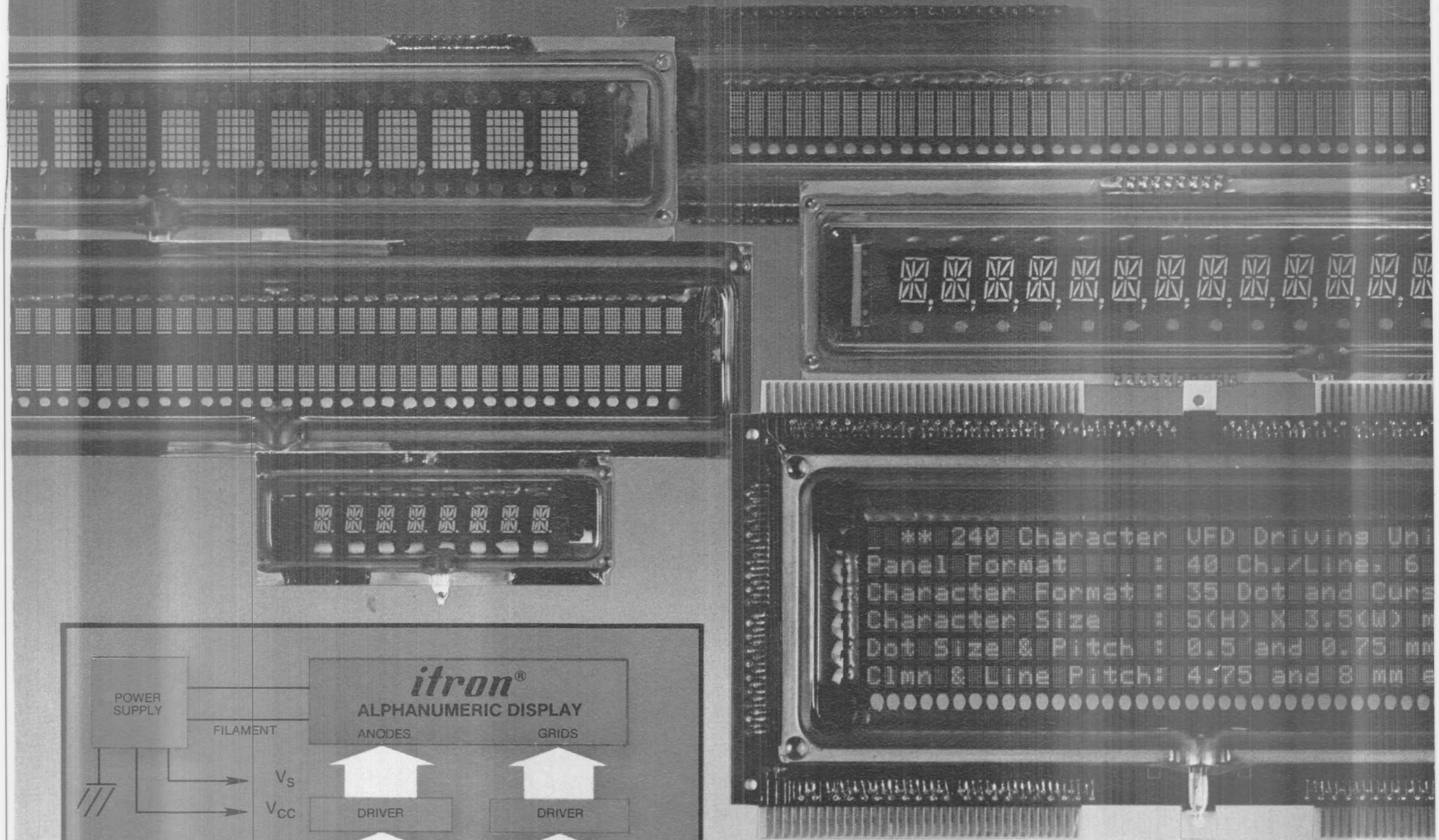

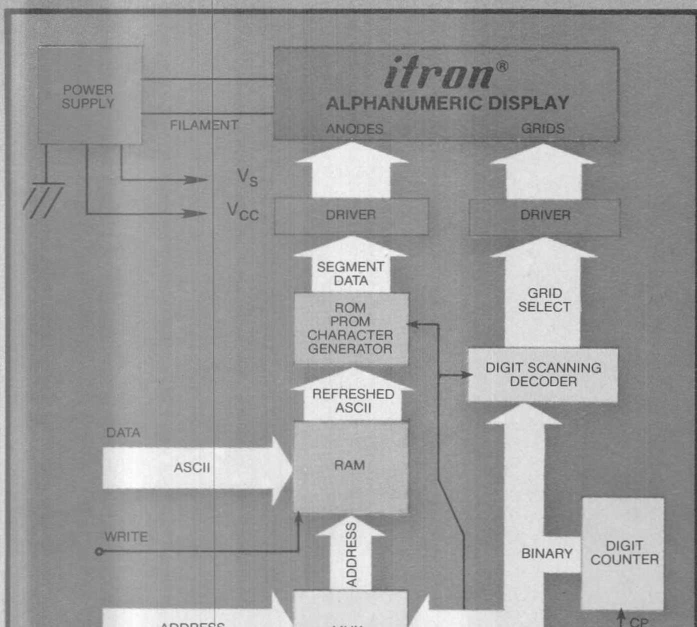

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Picture disk. Magnavox Consumer Electronics kicked off the video disk sweepstakes late in 1978 with its Magnavision system developed by NV Philips and MCA. The player relies on a laser to scan patterns of bumps and holes stored in a phonograph record–like disk.

of handball and jai alai. Charles Sporck, National's president, expected a market of 10 million units a year for electronic games and an average retail price of $29.95 by 1980.

But electronic games did not remain tied to the home television set. Mostek Corp. showed an electronic hand-held chess set in March 1976. The set was a calculator in which a chess algorithm had been stored and in which the player fed his moves; it retailed for $120.

Parker Brothers Inc. used a microprocessor in its first electronic board game, Code Name: Sector, a submarine chase-and-sink game that retailed for $35 to $40. Mattel Inc. introduced three hand-held games—football, auto racing, and missile attack—all retailing for less than $30.

Nor was the home television set useful only for games; it could also be employed as part of a home computer system. *Electronics* reported in November 1975 that hobbyists were creating a new industry. "Microprocessor-based computers in packages and kits sell for up to $1,000; makers have sold 8,000 in the past year," the magazine said. "And manufacturers are offering plug-compatible peripherals."

In August 1977 Radio Shack entered the personal computer market with a $599.95 system that became a big seller. It had a 12-inch cathode-ray-tube display, keyboard, and cassette tape recorder. The TRS-80 microcomputer system, built around Zilog Corp.'s high-performance Z80 microprocessor, came with 4,096 bytes each of random-access and read-only memory.

Throughout the decade electronics companies flirted with appliance manufacturers. In early 1973, for example, Frigidaire introduced an electric range that incorporated three MOS LSI chips.

Gradually electronic controls were added to other household appliances. In 1974, Whirlpool put an MOS control chip in a Sears Lady Kenmore clothes dryer, the first to use a chip for timing and logic control. In 1976, West Germany's AEG-Telefunken used two ROMs in a microcomputer to store 120 programs that could be used with hundreds of different recipes; the computer controlled baking, frying, grilling, and cooking. In 1978 Hamilton Beach put microprocessors in a food processor and a blender; the electronics not only controlled the machines' speeds but also helped the cook in converting metric measures into English ones.

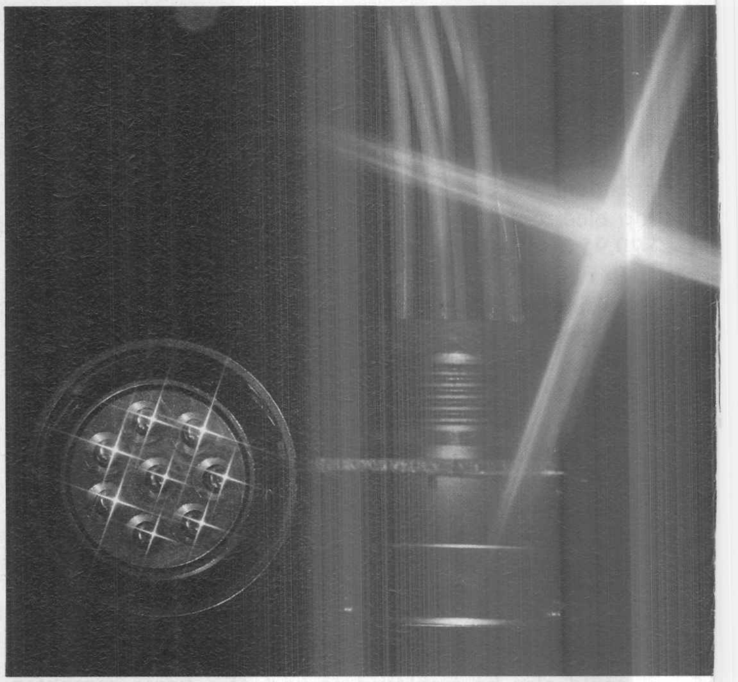
It was apparent at the beginning of the 1970s that there was a potential market for electronics in the automobile. Safety and pollution laws set engineers to work on electronic fuel-injection and ignition systems, air-bag sensors, electronic antiskid systems, and digital displays. But the auto makers were not satisfied with semiconductors. They complained at the International Solid State Circuits Conference in February 1974 that they needed more cost-effective and more reliable devices.

Federal regulations requiring emission control and fuel economy, however, drove automotive engineers to electronics. Designs included spark-timing control systems; exhaust-gas recirculation; fuel metering, or electronically controlled carburetors; and electronic fuel-injection systems.

By the late 1970s the auto companies were gradually relacing electromechanical parts, such as controls for the headlamp and windshield wiper, with electronics, and electronic ignition systems and voltage regulators were going into second and third LSI generations, primarily to gain greater integration.

It was clear by 1978 that on-board microprocessors were the only available technology able to control an automobile engine precisely enough to make it both cleaner and more efficient. Ford introduced the EEC-II system on 1979 cars; it controlled spark timing, exhaust-gas recirculation rate, and air/fuel ratio, based on inputs from seven sensors. The General Motors C-4 engine control system—introduced first on some Califor-

Interface. Connectors that could be handled easily were critical for the new optical-fiber technology to thrive. This connector from Amphenol North America division, Bunker Ramo Corp., illustrates clearly how each "light pipe" replaces the ordinary copper wire.



nia models due out nationally by 1981—kept the air/fuel ratio extremely close to stoichiometric conditions, thereby maximizing the catalytic converter's efficiency.

Color television manufacturers were working on shorter picture tubes at the beginning of the decade by increasing the deflection angle from 90° to 110°; this reduced the length of an 18-inch viewable picture tube some 4 inches. Engineers were also working on solid-state designs, although manufacturers were slow to adopt them because of the higher costs.

But rising consumerism made more reliable sets important. *Electronics* reported in June 1971 that many set makers were going to all-solid-state in their new models "because they feel the increased costs will be offset by the savings in warranty service bills."

By early 1973, television makers were deeply involved in reliability. Hardly a company failed to revamp its engineering procedures or organization after the advent of solid-state components and especially after linear integrated circuits began to be applied. And 1973 was the year of the picture tube.

Sony Corp. had one-upped everyone else's 110° tube with a 114° device in 1972, and in 1973 the Tokyo Shibaura Electric Co. (now Toshiba) announced a 118° tube for its 16-inch-diagonal receiver. Sony came back and said it could have a 122° tube in a 20-inch-diagonal set. In April 1974 GE-Sylvania introduced a new in-line color tube that could be fitted in existing chassis designs with practically no circuit changes. It was a 110° design with a large neck, in-line gun, striped screen, and slotted shadow mask.

By 1974 most television makers admitted the inevitability of all-electronic tuning. Magnavox reached the market first that June with a top-of-the-line chassis that integrated most remote control, tuning and display functions on a single 200-by-200-mil MOS chip. The Magnavox system featured a 6-inch-high channel number that appeared on the TV screen, then shrunk to a point and disappeared within 3 seconds.

A year later, in June 1975, *Electronics* reported that American TV set makers had three good reasons to design electronic tuners not only into high-priced consoles but also into 19-inch table models:

- The price was just about right.
- Some of the design problems associated with varactor tuners had been solved with new digital ICs.
- New features to attract consumers were more necessary than ever.

Total color set sales to dealers had fallen from 9,263,000 in 1973 to 7,830,000 in 1974 and were off again in 1975—the year-end figure was 6,486,000. Also, according to most estimates, fewer than 10% of the U. S.-made color TV sets in 1975 had electronic tuners, whereas nearly 100% of the color receivers made and sold in Europe had them.

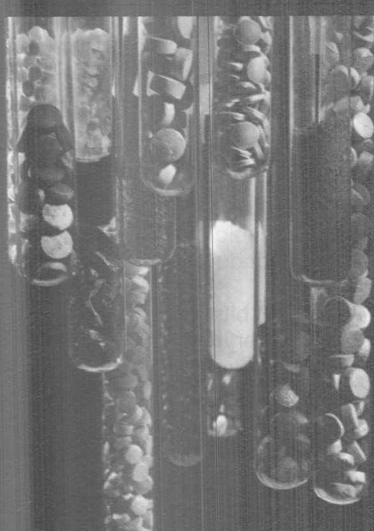
By February 1976, the "electronic magazine" was close enough to reality in Britain that it had a name, Teletext. The system began public trials, permitting home viewers to call up "pages" of printed information, such as news, sports and weather maps, on their specially equipped TV sets.

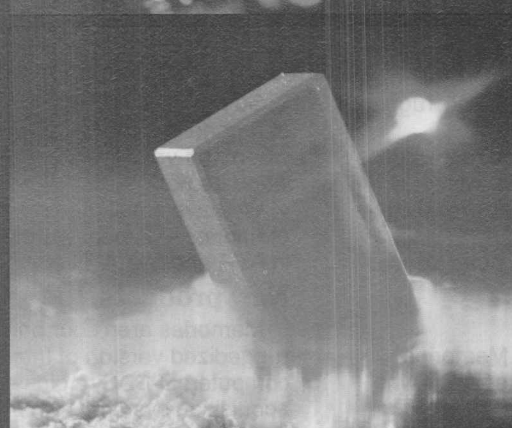
That fall's color TV sets contained some solid technical advances in station selection, color tuning, and tube designs. There were major changes in channel tuners, led by the German manufacturers. Large-scale integrated circuits were used in digital address systems, often in remote control units. Manufacturers used digital voltage-synthesis and frequency-synthesis techniques, as well as varied digital memory technologies.

In September 1977 Blaupunkt-Werke GmbH unveiled a color television set that turned itself on automatically according to instructions keyed in up to a year in advance. A standard three-chip F8 microprocessor from Fairchild automatically tuned the set's digital tuner to any of 19 channels. The microprocessor stored the dates and hours of as many as 20 TV programs, turning the set on and switching to the desired channel automatically.

In that same month two West Germans—Manfred Ullrich of Intermetall GmbH in Freiburg and Max Hagendorfer of Grundig AG in Fürth—described a way to provide a soundless inset picture on the TV screen along with the standard color picture. By January 1976 Grundig and the Sharp Corp. of Japan were marketing sets with black-and-white inset capability.

The industry knew that if it could solve the home video tape recorder's problems, there was a huge potential market. But in October 1971 a variety of consumer versions were being postponed as a lack of standards, technology problems, and proposed FCC restrictions on the rf radiation that video players could emit at broadcast frequencies all stalled progress. Eight different systems were available, all incompatible. Since the genesis of the industry, two systems have dropped out of the





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competition, the Ampex Instavideo and the CBS Electronic Video Recording (EVR).

Meanwhile the Japanese continued to work on video tape recording. At the end of 1974 there were four such home systems: a stripped-down Sony BetaMax for about $800, with a one-hour tape that sold for $13; the Video Home System recorder by the Victor Co. for about $890, with a two-hour cassette for $20; the VX-2000 by the Matsushita Electrical Industrial Co. for $730, with a 100-minute cassette for $26; and the V-Cord II from Toshiba and Sanyo for $1,150 and $1,220, with a two-hour cassette for $24.

In November 1976 the Japanese Government tried to pressure consumer video tape recorder manufacturers to adopt an industrywide standard. The pressure, however, was not strong enough, and in 1977 manufacturers began lining up behind one system or another.

Philips Gloeilampenfabrieken demonstrated a long-playing video disk in September 1972. It was a dramatic improvement over an AEG-Telefunken/Decca black-and-white video disk that had been demonstrated in 1970. Because the Teldec disks had grooves and mechanical tracking, they suffered from short playing time (an 8-inch disk played for only 5 minutes) and high record wear. The Philips disks held 30 to 45 minutes of color material and instead of grooves had submicrometer pits molded into a spiral track; a laser-generated light spot read the patterns.

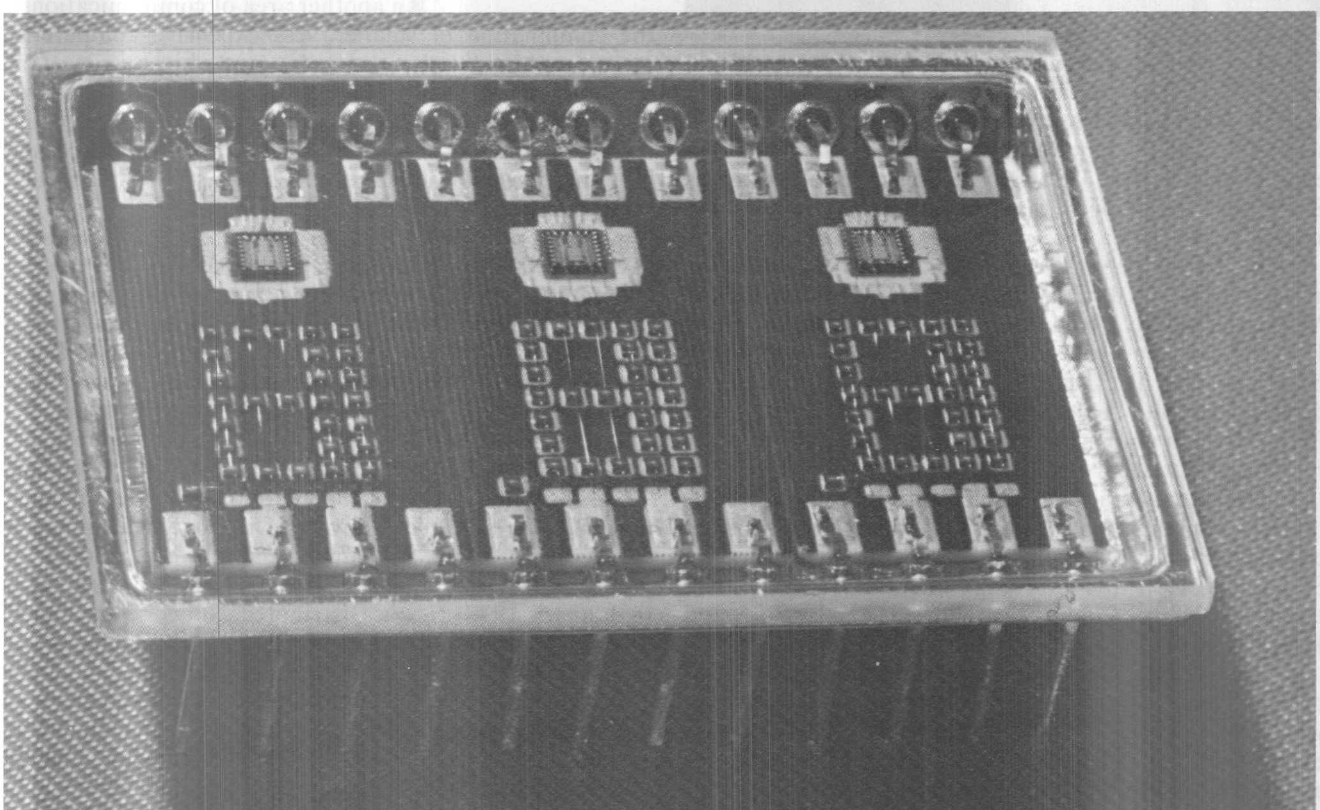
Two months later Telefunken demonstrated an improved Teldec video disk. The 8-inch disk now played for 10 minutes and produced a color picture, and the company said the system would be on the market by the end of 1973. Sales started in April 1975.

The Magnavox Consumer Electronics Co. introduced the first video disk system in the U. S.—Magnavision, in November 1978. A Philips design, the player cost $695 and the disks $5.95 to $15.95. RCA and the Japanese also announced systems. Sony had announced the first projection system in early 1972—the Sony Video Color Projection system, a 40-inch screen (50-inch diagonal). The projection unit was $2,000 and the screen $250.

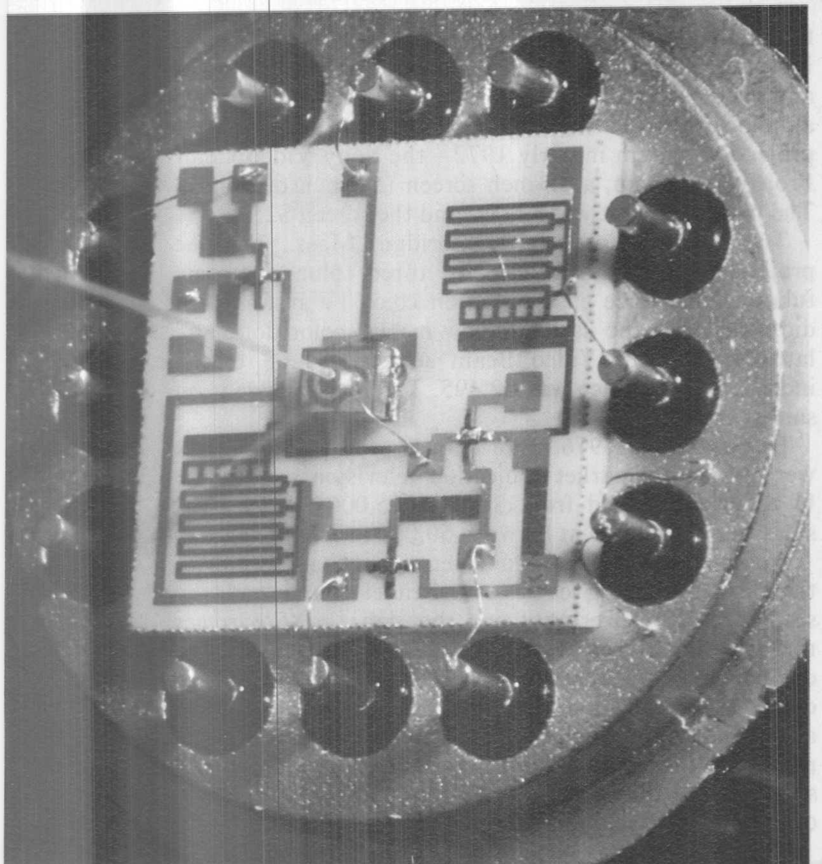
The Advent Corp. of Cambridge, Mass., put the projection optics inside each of three color electronic tubes to introduce a large-screen color TV system that did away with the usual shadow masks, color dots, and lattices. Advent's Video Beam screen was 68 by 51 inches, and the price was $2,495. The first sets went on sale at the end of 1973.

By September 1976 more than two dozen companies were trying to market projection television sets in the U. S. Prices ranged from $800 to $5,000, and annual sales were estimated at between 50,000 and 70,000 units.

Audio equipment manufacturers spent the first half of the decade fighting over four-channel sound and the second half recovering from the debacle. *Electronics* reported in March 1971: "Quad sound would help components and IC firms, but conflict between four discrete channels and the matrix approach threatens acceptance. The paucity of four-channel playback material, broadcasts, and equipment has limited public exposure. There's the question of which of several competing quadraphonic techniques will capture the audiophiles



Indicator. Light-emitting diodes were being fashioned into rugged displays for industrial environments and the military. This numeric indicator from Hewlett-Packard uses gallium arsenide phosphide emitters in a 5-by-7-dot matrix. Each numeral contains its own decoder/driver.



ing element in a thin-film preamplifier circuit in a TO-8 can. Invisible infrared laser will replace helium-neon laser light shown.

first, and whether the mass of two-channel stereo listeners will be willing to spring for the extra speakers and amplifiers." The issues were never resolved. More than a score of audio manufacturers offered four-channel equipment at the June 1971 Consumer Electronics Show, but consumers were unwilling to bet on one system over another. No units were marketed.

Nevertheless there were technological advances in audio equipment during the 1970s. H. H. Scott Inc. of Maynard, Mass., introduced a digital fm tuner in June 1971 that used a phase-locked servo loop to hold firmly onto a carrier. The Dolby B system helped the cassette deck become a true high-fidelity component, and Philips and a Japanese group developed other noise-reduction systems.

Japanese companies developed ultrahigh-fidelity digital stereo phonographs, with the audio signals pulse-code-modulated. Mitsubishi Electric demonstrated in September 1977 the first experimental system with a laser for playback, and it was followed soon by Sony and Hitachi Ltd.

By November *Electronics* was reporting that it was only a matter of time until all stereophonic recording would be done with digital techniques: "One acoustic engineer estimates that it will take three or four years for expensive consumer playback systems to catch on, another five or six more years before the price dips to the average consumer's level."

For radio, the decade brought a new craze that rejuvenated the industry: CB radio. The citizens' band boom flowered in 1973 during the nation's first taste of a gasoline shortage, when long-haul truck drivers used the small transceivers to ask fellow drivers where to locate dwindling fuel supplies. Drivers of private cars then swarmed into the CB market, installed sets, and with a lingo picked up from the truck drivers, began to flood the airwaves with casual conversations.

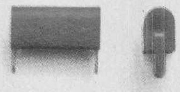
The Class D citizens' band had been set up in 1957 for quasi-business communications. It had taken 16 years to reach its first million users—this despite the fact that no licensing examination was required to operate the transmitters and receivers. By September 1975 there were 2 million CB users and by March 1976 there were 6 million. By the end of 1976, the total was estimated at 11 million, and potential users were clamoring for space in the crowded 27-MHz band.

But the fad peaked, and the market began to recede in 1977 when the FCC increased the number of available channels from 23 to 40 while a huge inventory of sets was on the shelves. Consumers were becoming increasingly aware at this time that CB was limited in range and that acceptable communication quality was an elusive achievement.

In another area of communications, the combination of smaller, less expensive computers, more sophisticated terminals, and improved data communications led to a trend in the 1970s toward distributed processing. As timesharing in the 1960s had increased access to computers, so did distributed processing, only it went one step further by actually placing a small computer at the user's site.

At first, users—such as service bureau companies—developed their own networking schemes. To assist them, computer vendors began to specify what hardware and software configurations could be constructed and what data communications should be used. Control Data introduced its Cyber 170 Network Products in March 1974, and the Digital Equipment Corp. unveiled its DECnet scheme in April 1974. When IBM introduced its Systems Network Architecture, or SNA, in September 1974, the concept gained momentum. Other mainframe makers soon followed: Univac's Distributed Communications Architecture was announced in November 1976; Honeywell's Distributed Systems Environment came out in January 1977; NCR's Distributed Network Architecture was introduced August 1977, and Burroughs Network Architecture as unveiled in October 1978.

A significant satellite communications development of the seventies was the plan of a new company, Satellite Business Systems, for an all-digital system to handle office communications. Backed by IBM, Comsat, and the Aetna Insurance Co., SBS in December 1975 proposed its satellite system in the 12-to-14-GHz region of the spectrum. The plan called for sending on demand voice,



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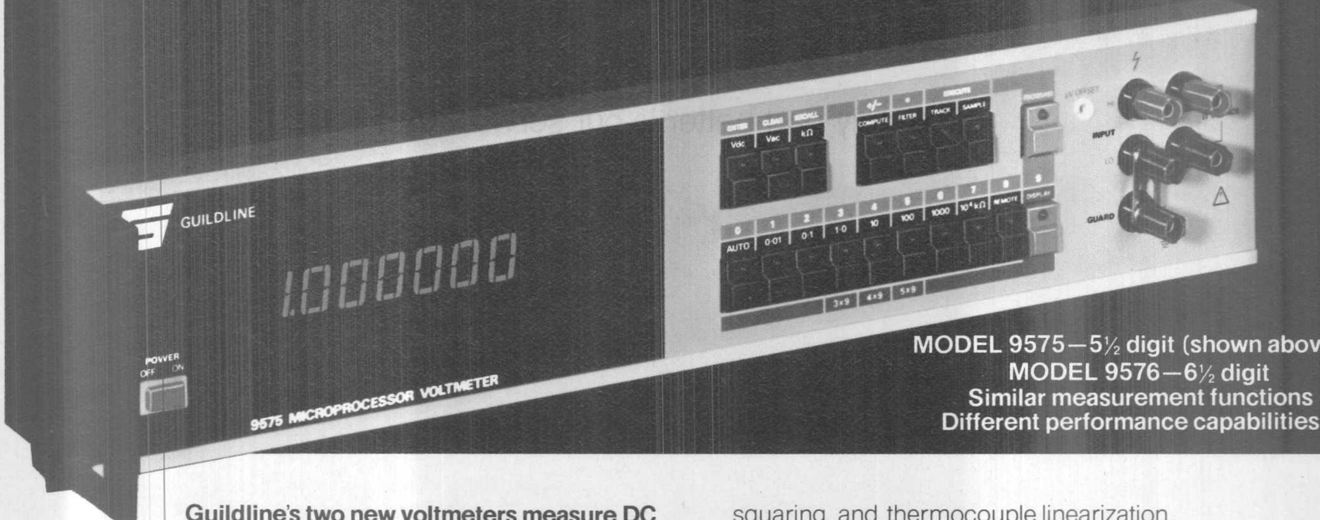

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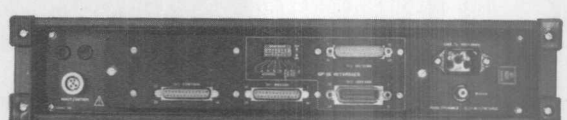

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video, or data to anyone hooked into the system, which would bypass the usual common carrier.

Competition was soon promised by AT&T, which announced it would provide its own option, the Advanced Communication Service. The phone would hook up all home and office voice, video, and data machines into one gigantic terrestrial-based system.

The two plans became tangled in a Federal Communications Commission regulation web concerning which should be allowed to do what and for whom. To complicate matters, Xerox got into the act in 1978. It proposed the XTEN system to link office equipment through a combination of land lines, microwave links, and leased channels on satellites. This 10-GHz offering also got tangled in the regulatory system. By the end of the decade, no decision had been reached on any of the new satellite business services.

But satellite communications advanced in other areas. Early in the 1970s there were but two satellite systems serving North America alone: Telesat Canada's Anik and Western Union's Westar. This situation changed rapidly. RCA Global Communications soon launched a satellite. And in another approach to entering the business, the American Satellite Corp. leased channels from Western Union and sold time to customers.

By the early 1970s Intelsat 4 satellites were being launched. These used two separate beams, aimed at the eastern and western regions of the Atlantic Ocean. They provided transatlantic communication by using the same 500-MHz slots at 4 and 6 GHz. There were six Intelsat 4 satellites in orbit in 1975 in response to increasing demand for service. For every transatlantic telephone call made in 1974, 10 were made in 1975. Also in 1975, ships at sea got satellite service when the first Marisat (for maritime satellite) was launched.

To handle cable television, RCA put up Satcom 1 and 2 by the end of 1976, and with the FCC's permission, AT&T and GTE launched a satellite system to handle long-distance phone calls in the U. S. Two of the latter satellites, both named Comstar, were launched in 1976 and a third in 1978. Each operated in the 4-to-6-GHz band, and each could handle 30,000 simultaneous calls.

As the decade closed, still more applications appeared for satellite technology. In Canada, for example, the pages of a weekly newspaper were transmitted from Europe to Montreal via satellite. And in the U. S. the Bell System developed an integrated circuit to remove speech-disrupting echoes from telephone conversations carried by satellite. Previously this had been done by expensive echo-canceling or echo-suppression systems.

In ground communications, the 1970s saw the first practical steps toward fiber-optic systems. Low-loss fibers were invented, and more powerful sources and detectors of light became readily available.

From thousands of decibels per kilometer in the sixties, the attenuation of step- and graded-index fiber had by 1970 dropped to about 20 dB/km at a wavelength of 6,328 angstroms. This feat was accomplished by Robert D. Maurer of Corning Glass Works in Corning, N. Y. At the same time Nippon Electric Co.'s Central Research Laboratory in Kawasaki, Japan, made a graded-index optical fiber with attenuation of approximately 20 dB/km. And C. K. Kao at International Telephone and Telegraph's Standard Telecommunications Laboratories in Harlow, England, developed a 100-megabit-per-second transmitter-receiver system wired up with multimode low-loss fiber.

Decisions. Microprocessors gave digital communications nets many new capabilities. In 1975, Codex Corp.'s 6000-series Intelligent Network Processor examined data and made transmission decisions without customized programming and at radically lower cost.

Actual fiber systems were being tested for practicality in the early years of the decade, to see just what the operating tradeoffs might be. Among the most highly interested users were the military services. Besides their need for large bandwidths, which the fibers provided, the armed services were intrigued by fiber's total immunity to electromagnetic interference.

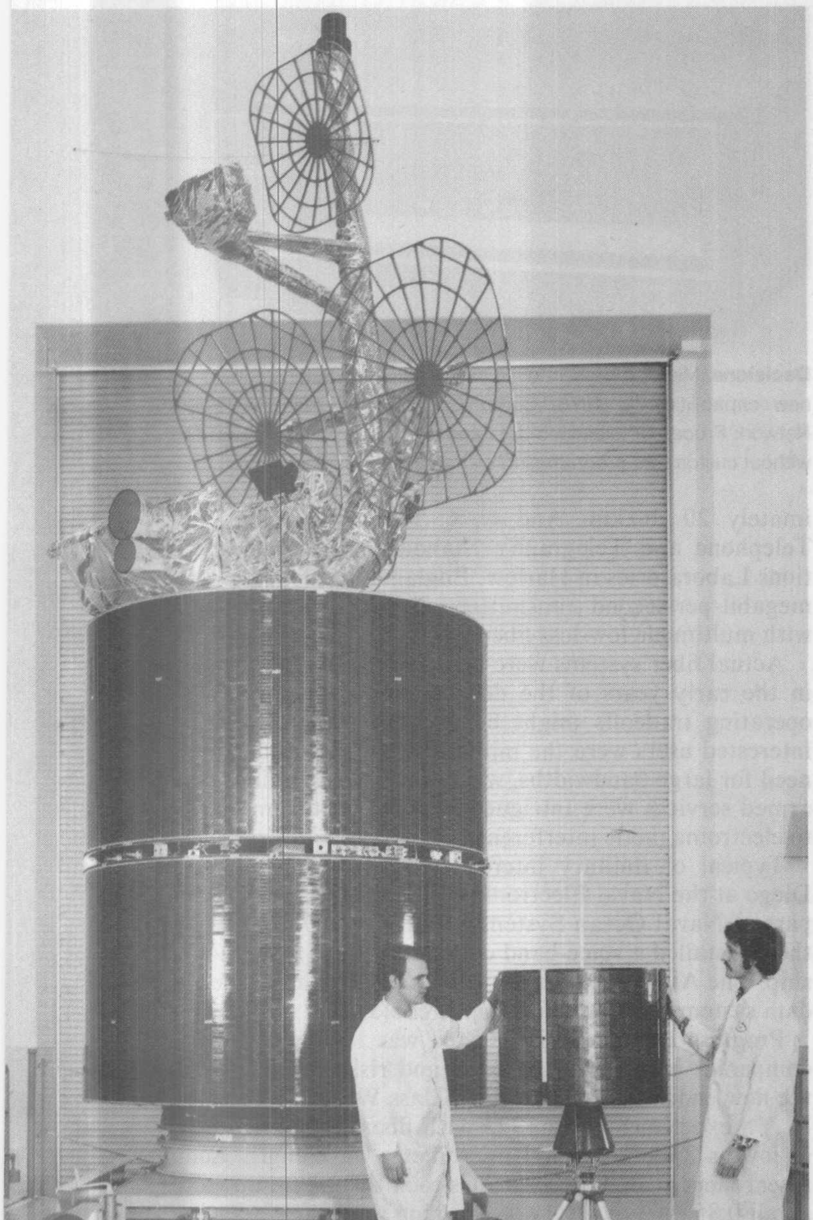
Typical of military interest was work done in San Diego at the Naval Electronics Laboratory Center (later part of Naval Ocean Systems). Early in 1974 engineers there installed a voice-band communications system on a ship. The Air Force that same year test-flew multiplexed data systems that used fiber-optic cables.

Progress in the civilian sector was led by the large companies because of the costs and risks involved with the new endeavor. The Corning Glass Works in Corning, N. Y., experimented in 1973 with fibers that had losses as low as 2 dB/km at a 1-micrometer wavelength. Soon researchers at Bell Laboratories took this figure down to about 0.85 dB/μm. By 1979, Corning was manufacturing fibers with 0.7-dB/km losses at a 1.3-μm wavelength.

In mid-decade fiber came out of the laboratory and into the operating environment. Typical was a Bell Laboratories' experiment in January 1976 that demonstrated the feasibility of mass-producing fibers. Bell engineers showed that cables of 144 single fibers could be made and mass-spliced without individual handling. These cables—only ½ inch in diameter—could handle almost 50,000 simultaneous telephone conversations.

By this time some smaller, more specialized companies were getting into the act. Teleprompter Manhattan Cable Television capitalized on fiber's broad bandwidth to set up a system to carry multichannel television signals from a studio to a cable television distribution point some 800 feet away.

And in an experiment in the "wired city" concept, the Nippon Telegraph and Telephone Public Corp. in Japan



Related. As satellite communications grew, so did the satellites. In 1975, Hughes Aircraft engineers showed off two of theirs, the 10-year-old Early Bird, which had 240 two-way channels, right, and the upcoming Intelsat IVA, planned for 11,000 channels.

set up a fiber-optic network to provide residential video information to 300 subscribers in a model city near Osaka. Not to be outdone, the English ITT subsidiary, Standard Telephones and Cables Ltd., successfully sent 140-Mb/s data over a 9-km link at Harlow in 1977. Similar efforts by Philips Gloeilampenfabrieken and by the Centro Studie Laboratori Telecommunicazioni SpA of Turin were successful in the Netherlands and in an experiment in Italy. All of these systems operated at a rate of 140 Mb/s.

By 1979 NTT had the fiber's loss down to 0.20 dB/km, and Bell Laboratories had its fiber's digital data rate up to 200 gigabits per second—at least in the laboratory.

The usual laser for fiber systems was a gallium arsenide diode. Such a device could convert direct current into highly monochromatic light beams. And this light could be readily modulated by variations in the diode drive. In 1972 IBM researchers produced a GaAs laser that could generate a beam of light only 2 μm in diameter. This was small enough to couple all of the laser power into the thinnest of single-mode optical fibers. These fibers, in turn, had the lowest attenuation, which meant that fewer amplifiers would be needed in the transmission line. The IBM researchers got their laser to handle digital data rates in excess of 100 Mb/s.

By mid-1977 Bell Laboratories was reporting major increases in diode lifetime. This had been a major problem, but now lasers with projected lives of 1 million hours were being made.

RCA announced a planar laser diode in June 1979 that could be mass-produced by integrated-circuit fabrication techniques. It was generally agreed that if optical communications were to become commonplace, the systems would have to be integrated and produced much as ICs are. During the 1970s much research aimed at developing such integrated devices by depositing dielectric layers on glass substrates.

But perhaps the most exciting optical device of all was Bell's experimental Fabry-Perot resonator late in the decade that performed so many tasks it was almost a universal optical element. The lithium niobate-based device could be used as a logic element in memories, since it acted as a bistable switch when driven by suitable optical signals. It also functioned as a pulse shaper, or limiter, or differential amplifier. Furthermore it could work as an optical triode, performing the functions of an electron tube.

With the closing of the 1970s, the electronics industry could mark 50 years of progress. Starting with expansion of the vacuum-tube radio in the thirties, it had rushed past such milestones as radar, television, analog and digital computing, satellite communications, and semiconductor technology, all the while churning out new ideas and equipment for basic markets like instruments, optoelectronics, industrial electronics, military electronics, consumer electronics, and avionics.

There were no signs of an industry in sedentary middle life or approaching old age. Already there was talk of the "real" electronics era of the coming 50 years:

- The virtual abolition of paperwork in offices by terminals and computer storage.
- The cashless society, with bank computing systems linked to terminals at all the major retail outlets.
- The personalized phone call—the Picturephone would re-emerge in more practical form.
- Electronic mass transit—magnetic levitation and other schemes would receive serious attention as fossil fuels became prohibitively expensive.

There were many more dreams, but these are best left to visionaries and to future generations of practical engineers. The electronic genie was out of the bottle, and further progress was guaranteed. □

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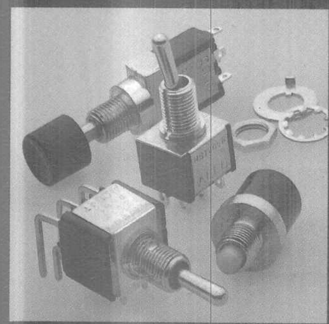

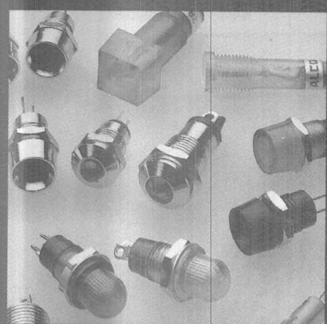

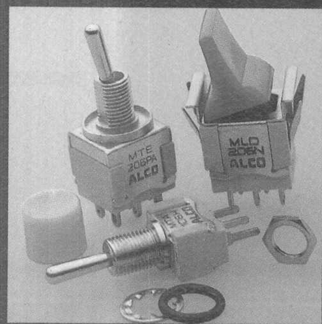

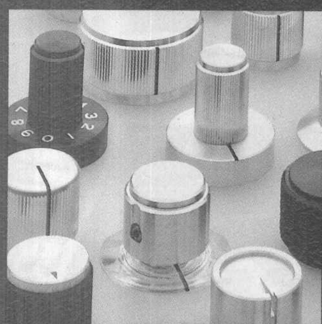

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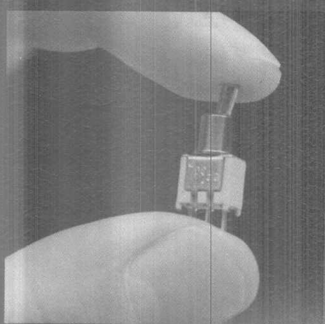

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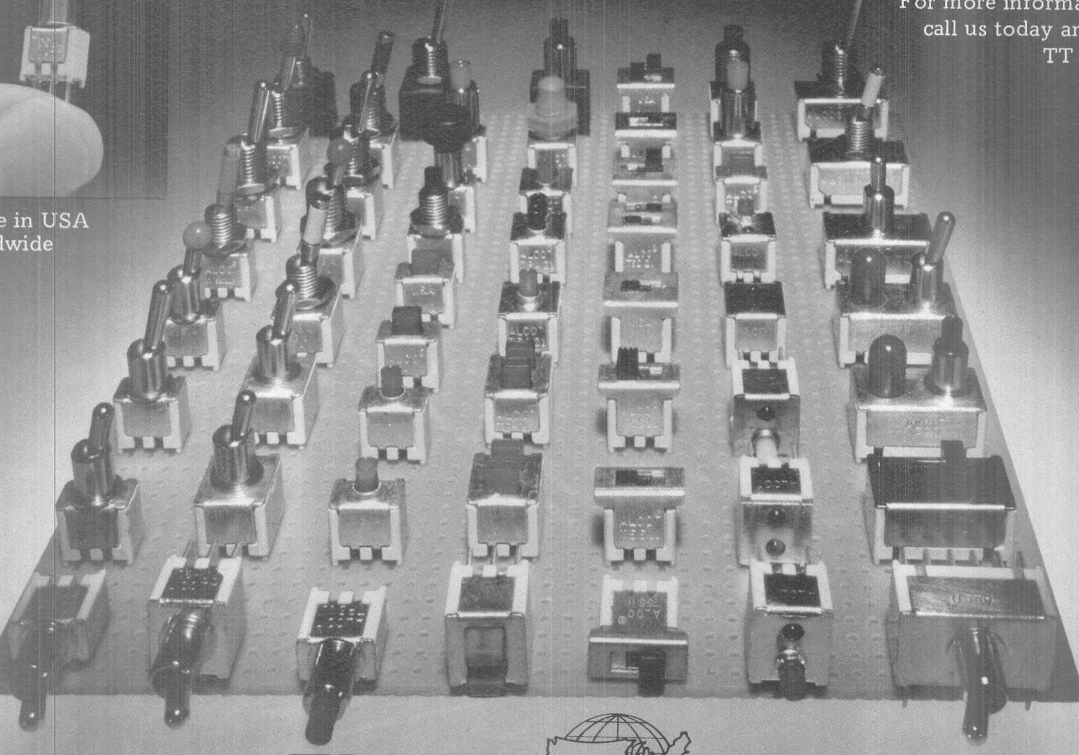

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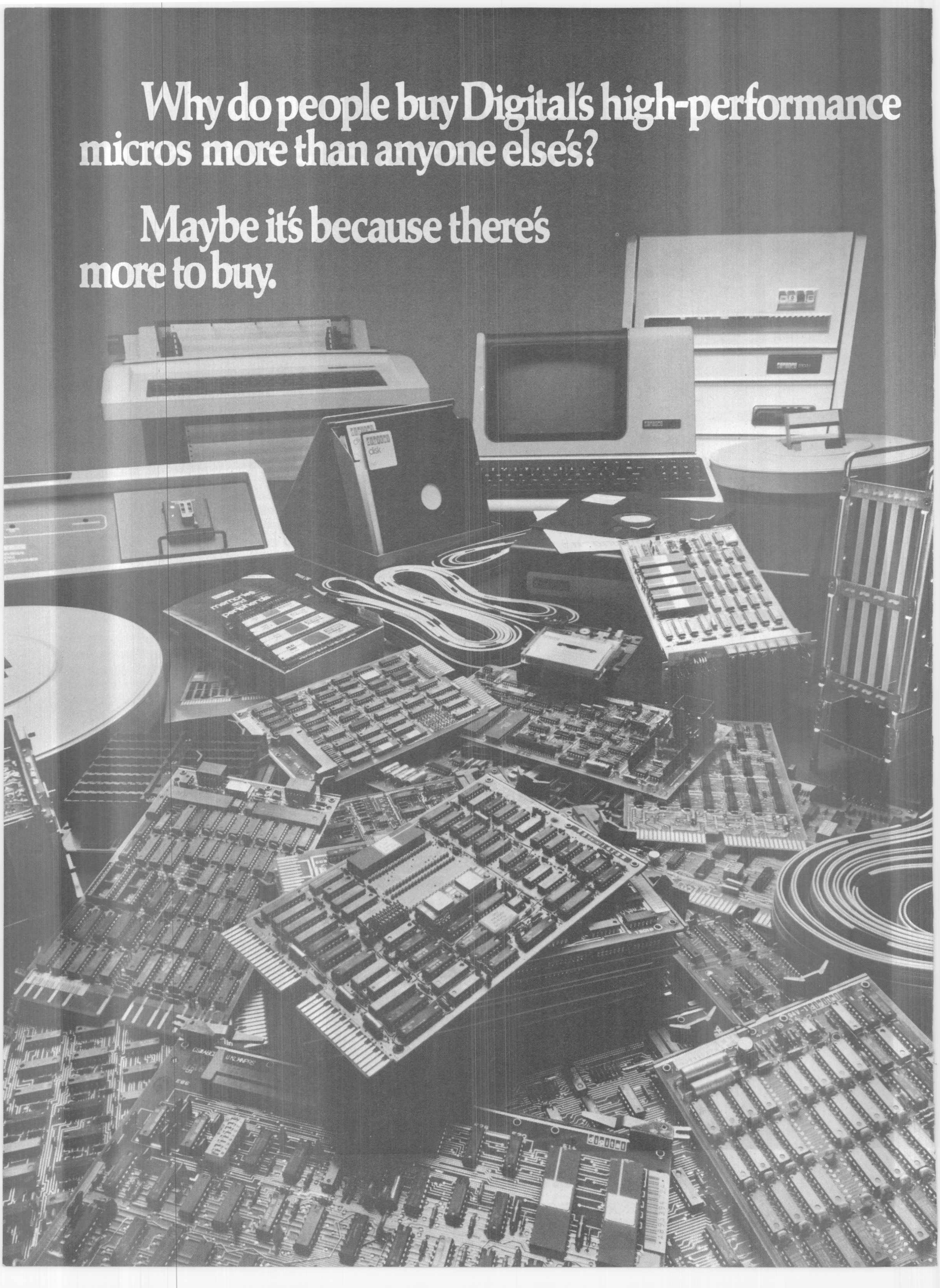
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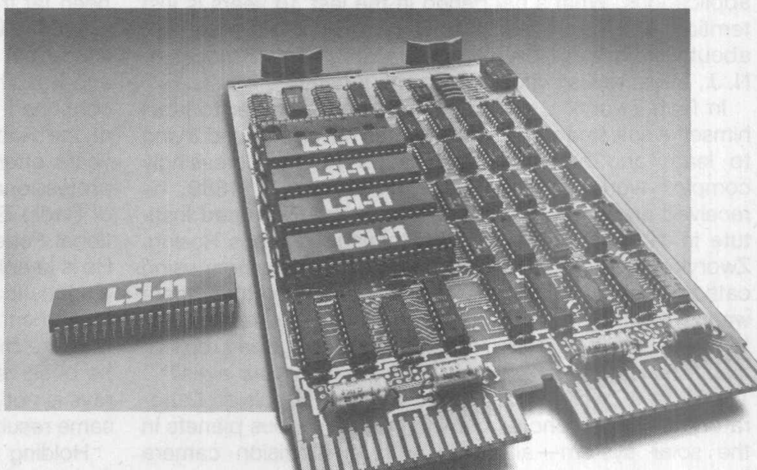

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GREAT INNOVATORS

VLADIMIR KOSMA ZWORYKIN

"I'm still learning," says Vladimir Kosma Zworykin. Given the hectic pace of developments in his field, that's no mean feat for the 91-year-old inventor of television. "Mostly I'm learning about electronics and electronic applications. What's happened in the last 10 years is just terrific." And the piles of books and journals scattered about his office at RCA Corp.'s research labs in Princeton, N. J., attest to his curiosity and enthusiasm.

In fact, Zworykin, who does not know whether to label himself a salesman or a scientist, has never stopped trying to learn and apply his knowledge to an increasingly complex world. Born in Mourom, Russia, in 1889, he received an undergraduate degree at the Petrograd Institute in 1912. There, under the tutelage of Boris Rosing, Zworykin began his work with an electronic system using cathode-ray tubes for television. "At the institute, there wasn't a lot of interest in electronic TV," he reminisces. "They said, 'you're trying to replace the eye' and I replied, 'can you see the far side of the moon with your eyes?' " These days Zworykin is often at the Jet Propulsion Laboratory to see the photos coming in from various planets in the solar system—all taken with a television camera based on the one he designed over 50 years ago.

Later in 1912 Zworykin began research in X rays under Paul Langevin at the College de France in Paris; he was interrupted by World War I, returning to Russia to serve as an officer in the signal corps. After the war he emigrated to the U. S., becoming a citizen in 1924 and receiving a Ph.D. from the University of Pittsburgh in 1926.

Zworykin did much of the developmental work on the iconoscope (a type of television pickup tube for picture transmission) and the kinescope (the television picture tube itself) while at the Westinghouse Electric and Manufacturing Co. In 1929, with the support of David Sarnoff, he joined the then Radio Corporation of America as director of its Electronic Research Laboratory.

Though he retired from the company in 1954, he has been far from idle for the last 25 years. While still actively at RCA, Zworykin had helped to take the electron microscope out of the lab and into medical research centers and hospitals, and this interest in medical electronics has continued. He was director of a medical electronics center at the Rockefeller Institute in New York for a number of years after retiring, as well as national chairman of the professional group on medical electronics of the Institute of Radio Engineers and founder-president of the International Federation for Medical and Biological Engineering. He is keenly aware of how much electronics could improve diagnostic work in medicine. "Some types of electronic equipment would allow measurements of bodily conditions that are much more accurate than those possible now," he observes. "But few are used. Also, excessive use of X rays is not recommended, and doctors can get almost the same results using microwaves."

Holding over 100 patents—for inventions including the snooperscope and sniperscope infrared image tubes developed during World War II, guided missiles, and automatically controlled cars—and nearly 30 awards—including the National Medal of Science and the Founders Medal of the National Academy of Engineering—Zworykin has shown an avid interest in many areas of electronics. He can still be found several days a week at his office at the RCA labs in Princeton corresponding with fellow scientists, reading recently published papers, or consulting with younger RCA researchers. What is he doing? "I'm starting at the beginning again," he says with a twinkle.

FREDERICK EMMONS TERMAN

What is now Silicon Valley owes a lot to Frederick Emmons Terman. As teacher and administrator at Stanford University for more than four decades, he was the catalyst that transformed the San Francisco bay area into one of the world's leading centers for electronic innovations. Although characteristically he plays down his role, no other academician has proven better able to synthesize the interests of Government and industry with those of a university. He also wrote the standard text of its time on radio engineering.

Terman's tenets were new when he began practicing them after World War II, first as dean of the School of Engineering and later as provost. They were:

□ Open the university's research laboratories to Government projects so that students can work on advanced technology.
□ Educate good engineers so that local companies can employ them to grow and prosper.
□ Respond to local industry needs.
□ Attract top-flight faculty.

The emergence of Stanford as an excellent engineering school and the rise of companies like Hewlett-Packard Co. and Varian Associates are but a few of the results. William Hewlett and David Packard were both Terman's students, as are many of the who's who of the electronics industry.

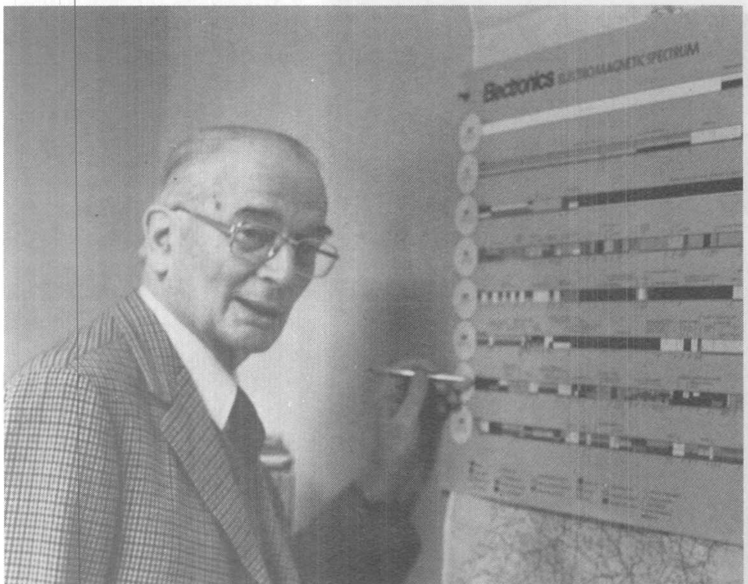
"As a boy growing up, I learned a lot about how a university functions," Terman recalls. He arrived on Stanford's campus as a 10-year-old when his father joined the faculty as a professor in 1910. Since then, he has been away from the campus for only two periods of any length. One was to earn his Ph.D. in 1924 from the Massachusetts Institute of Technology. The other was to run a large top-secret radio research laboratory during World War II in Cambridge, Mass., an experience that crystallized his thinking on how to integrate technology with Government research and university laboratories.

"I got the benefit of other people's thinking, particularly Harvard's," Terman says, on how to grow a strong engineering school. When he returned to Stanford in 1946 as engineering dean, bringing several laboratory colleagues back with him, he recalls that "there were half-finished jobs at the end of the war, devices weren't perfected. There was a clear need [for the Government] to finish them." He was soon approached by the then new Office of Naval Research and started off with three projects. The one in chemistry flopped, he relates, but the one in physics led to a Nobel prize for Felix Bloch, who discovered nuclear magnetic resonance, and the one in electrical engineering became the start of Stanford's nationally recognized program in engineering research.

However, "I think that the books I wrote had the most influence," Terman declares. They certainly helped him gain a national reputation as an educator. A radio ham in his youth, Terman wrote "Radio Engineering" in 1932—"the first really good textbook in radio engineering," he says proudly. "That book was used everywhere, even translated into foreign languages." Then in 1941, he completed "The Radio Engineer's Handbook," which has often been called the Bible of the field.

In that year, too, he was made president of the Institute of Radio Engineers (now the Institute of Electrical and Electronics Engineers), the first one to be elected from the West Coast.

Retired from the University since 1965, Terman, a widower, lives on campus in his spacious home with its lovely gardens. He believes that electronic technology will keep "steaming right along in integrated circuits, making an honest difference in people's lives."



MAURICE PONTE

Maurice Ponte, who started his career as a research scientist and eventually rose to the top position in France's premier professional electronics company, contends that the first true forerunners of modern radar technology came out of the laboratories of La Compagnie Générale de Télégraphie sans Fil (CSF) in the early 1930s.

It is Sir Robert Watson-Watt of Britain's National Physical Laboratory who is generally credited with the first use of radio waves in detecting objects at a distance. Watson-Watt began using radio-detection finders to spot for the Royal Flying Corps (later the Royal Air Force) during World War I. Radios then operated in the high-frequency band, where wavelengths are measured in meters; higher frequencies could not be handled.

At this time Ponte was still a boy. By the time he was working on magnetrons in the early 1930s, the frontier for frequency had moved up to the ultrahigh-frequency band of decimeter wavelengths. By 1935, Ponte and his co-worker, physicist Henri Gutton (whose father, also a physicist, had experimented with detection by decimetric waves as early as 1927), had a rudimentary radar aboard the French freighter SS Oregon. Intended mainly to detect icebergs, it operated well up in the uhf band at wavelengths of 80 and 16 centimeters.

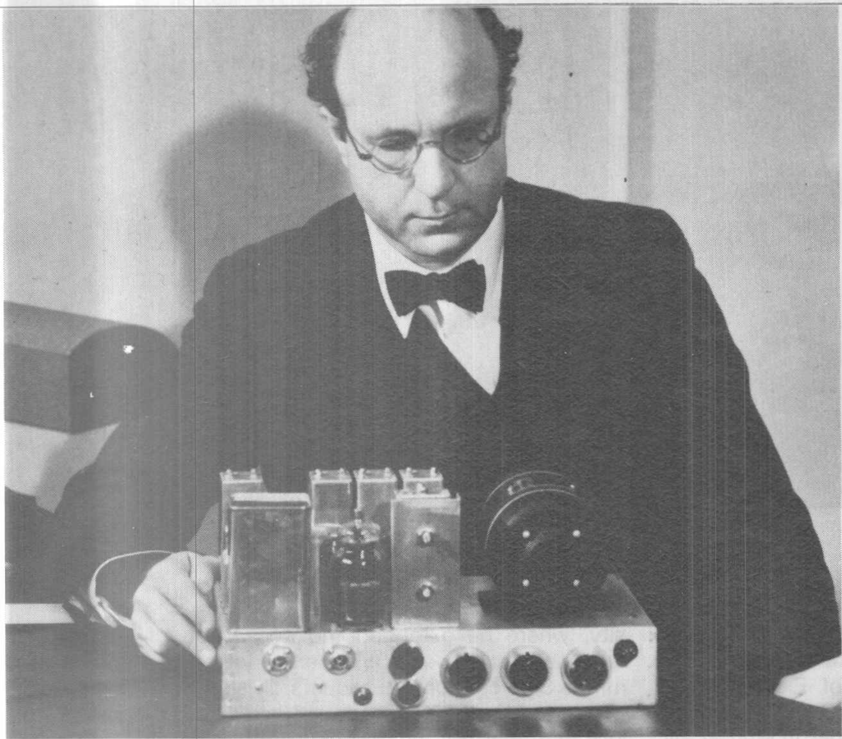
Although Watson-Watt and Ponte were working with different frequencies, the two in a sense were on the same wavelength by 1935. In February of that year Watson-Watt submitted to the British Air Ministry, which had asked him to look into the feasibility of an electromagnetic death ray, a memorandum entitled "Detection of Aircraft by Radio Methods." In March, Ponte and Henri Gutton put together a "Note sur le Repérage d'Objets Mobiles par Ondes Ultra-courtes et sur ses Applications Immédiates à la Défense Nationale." They proposed setting up radar bases along the Rhine to pick up movements of German warplanes, using metric waves for detection at ranges out to 100 kilometers and decimetric waves for short-range precision at 10 km.

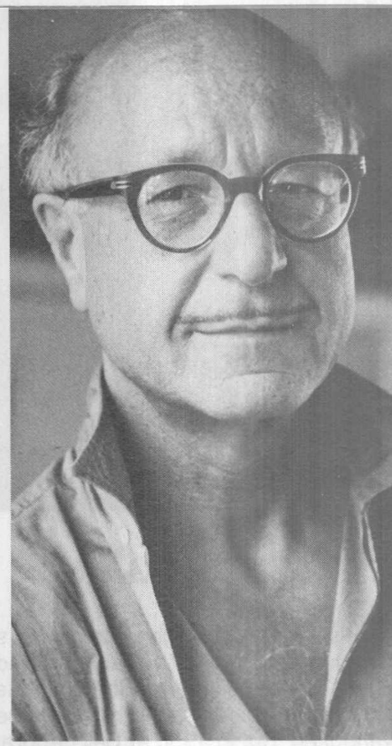
Throughout the 1930s, Ponte and Gutton kept improving their magnetrons at the CSF laboratory on the outskirts of Paris at Levallois. Ponte had set it up in 1929, leaving a faculty post at the prestigious Ecole Normale Supérieure—his alma mater—to do so. In 1935, the CSF team turned out what Ponte considers a landmark design—a tungsten cathode surrounded by resonant anode segments. "This tube presaged modern magnetrons with resonant cavities," Ponte explains. "It developed 10 watts continuous wave at 16 centimeters or 7 W at 8 cm—not much now, but very impressive at the time." Further advances in tube technology made it possible for CSF to push the output power of its magnetrons to 50 W peak at 16 cm (1,875 megahertz) by 1939.

Then came World War II and a go-ahead for the radar warning network the Army brass had scoffed at four years earlier. Hitler's blitzkrieging armies overran France before the project was completed, but the high-power magnetrons Ponte and Gutton had developed for precision short-range detection nonetheless aided the Allies against the Germans. On orders from the French High Command, Ponte, mobilized as an artillery captain, carted two tubes across the English Channel in May 1940 and turned them over, with the know-how to build them, to researchers at the Wembley Laboratories of the General Electric Co. (no relation to the similarly named U. S. company).

Back in occupied France, Ponte spent the war clandestinely continuing to improve his magnetrons—in one close call, a German general inspected CSF's tube plant. Nevertheless, Ponte and his crew had CSF ready to become a world-class producer of high-frequency tubes after the war. Thomas-CSF, the organization that resulted when Thomson-Brandt took over CSF in 1968 and made it a division of the parent company, still remains in the top rank today.

Ponte, who had been president of CSF for seven years previous to the merger, left the company then to found the Agence Nationale pour la Valorisation de la Recherche (Anvar), a government agency charged with improving the transition of discoveries made in government laboratories to applications in industrial products. Ponte ran Anvar until he retired in 1971 at the age of 69.





DANIEL E. NOBLE

Before the advent of the mobile two-way radio telephone system, roadside phones swallowed a lot of nickels from police patrollers and motorists in distress. To Daniel E. Noble, a pioneer in fm radio and solid-state technology, goes the credit for the design and development of the mobile system for the Connecticut State Police in 1940.

Noble's distinguished career in electronics, spanning more than five decades, began in 1923 at Connecticut State College, Storrs (now the University of Conn.), where he received his BSEE degree and spent 17 years as student, teacher, and consulting radio engineer. With additional studies at Harvard University and the Massachusetts Institute of Technology, Noble is remembered for his ground-breaking work in fm radio while at Connecticut. As designer, builder, and operator of the a-m college station that sent programs from Storrs to Hartford over local stations, Noble modified the system to fm between 1936 and 1938. This work was followed by the design of one of the first fm stations for radio WDRC in Hartford.

Noble's work attracted the attention of Paul O. Galvin, owner of the company that was later to become Motorola Inc. Galvin was able to persuade the Connecticut professor to join the Chicago firm in 1940 as director of research. "I didn't know whether I'd like the industrial world or not, so I took a year's leave of absence," the 78-year-old Noble recalls today. "But I soon discovered that I was able to make very real and rapid contributions at Motorola, and it hadn't been six months before I decided to stay."

Noble has spent the remainder of his career with Motorola, where among other things he is credited with:

□ The concept and direction of the development of the U. S. Army's SCR-300 fm Walkie-Talkie in 1942.

□ The decision initiating Motorola's establishment of major operations in Phoenix, Ariz., where Noble in 1949 set up and headed a research laboratory in the infant field known as solid-state electronics.

□ The initiation of work that led to invention of the power transistor.

The holder of nine patents and recipient of numerous engineering awards, Noble stepped down as vice chairman of the Motorola board and chief technical officer in 1970 to move into semiretirement as chairman of the company's science advisory board. He maintains offices in that capacity today in Motorola's original Phoenix plant, erected in 1950.

Noble has been a philosopher and painter in recent years, and his work reflecting his view of man's interaction with technology and today's complex society is prolific. Among the challenges faced by EEs today, he notes "the complexity of a field that has grown so much that it's difficult to know which direction to take. . . . in my day, I was able to contribute because I was effective in identifying patterns that were needed and moving accordingly. But today it's much more difficult."

Noble is not pessimistic, however. In fact, he sees sophisticated computer modeling techniques and the "extention of brainpower" made possible by computers as the ultimate way to regain control of a world that is rapidly growing too complex to handle. Eventually, he says, the electronics industry will "go into fundamentals of molecular and light forces far beyond today's circuitry."

[EDITOR'S NOTE: Daniel E. Noble died at the age of 78 on Feb. 17, 1980.]

C. LESTER HOGAN

Because C. Lester Hogan has played such an outstanding managerial role, most notably in leadership positions at Motorola, Fairchild, and the Institute of Electrical and Electonics Engineers, his role in research is sometimes overlooked. But in 1950 at Bell Laboratories in Murray Hill, N. J., Hogan built the first microwave gyrator, isolator, and circulator on a single circuit, passive nonreciprocal elements without which microwave communications would be impossible.

A graduate of Montana State University in 1942 with a bachelor's degree in chemical engineering, he served as a Naval Officer in World War II prior to earning master's and doctorate degrees in physics from Lehigh University. In August 1950 he became a member of Bell Laboratories' technical staff where "a guy set out to develop something and did so in a very short period of time," he states.

Working in the Physical Research department, Hogan came across an article written by B. D. H. Tellegen, a member of the Dutch Philips organization, who developed a four-pole network, or gyrator, that was in effect a one-way transmission system. Hogan set out to build some similar devices and found that the physical phenomenon on which Tellegen's work was based was known in optics as Faraday's rotation of planar polarization.

At this point, Hogan sought the help of Bell Labs' William Shockley, who immediately began writing equations that showed him he needed materials with a large rotation at optical frequencies. "Magnetic materials will do it," said Hogan, seeking aid from Bell's chemistry department in developing a very weak magnetic material with low dielectric loss.

"By Nov. 1, all the pieces fit together," he recalls. "They thought I was a genius," he adds, "but I had just put together everything that existed."

Hogan knew the circuit elements were very powerful tools that would be used in microwave systems: "Today, there's not a single microwave system that doesn't use these devices. In fact, there are 200 on Intelsat 5."

Nearly three years later, Hogan accepted the position of associate professor of applied physics at Harvard University, where he extended the knowledge of ferrites. He remained until June 1958, when he joined Motorola Inc. to run its Semiconductor Products division in Phoenix, Ariz., which had had sales of about $3 million and a similar net loss that year. By the end of 1959, the division had sales of $10 million and was profitable. "That took me longer than three months, so I must have been getting older and slower," jokes Hogan.

In 1968, the year Hogan left Motorola to become the president and chief executive officer of Fairchild Camera and Instrument Corp. in Mountain View, Calif., Motorola posted a profit of about $25 million on sales of about $200 million. Largely responsible for that growth was a gamble Hogan took on epitaxial processing. "Using Bell designs, we made the first commercially available epi devices, Mesa transistors. They were much better than non-epi devices," Hogan says, "and sales skyrocketed."

Today, the 60-year-old Hogan is the technical advisor to the president of Fairchild Camera and Instrument Corp., as well as executive vice president of the Institute of Electrical and Electronics Engineers. He also serves as a member of the board of directors of about half a dozen corporations and on the scientific and educational advisory committees of several universities.

Despite his active schedule, Hogan has time to reflect on his experiences. "It was very exciting and thrilling. None of us visualized the impact we would have on the electronics industry, but we knew it was going to be great." However, he continues, "it wasn't the golden age of electronics. That still lies ahead of us."

"When I went to Bell Labs in 1950," Hogan recalls, "IBM's 701 was the first commercially available computer. Even the simplest of today's microprocessors will outperform that system. Today, the future is overwhelming. My mind is boggled by the potential of VLSI. It is the greatest revolution and it will allow us to do things that were totally impractical before. For years, I've been talking about the pervasiveness of electronics. Finally, it is coming," he states. "A cost barrier had to be broken, and it was done with LSI and the microprocessor."

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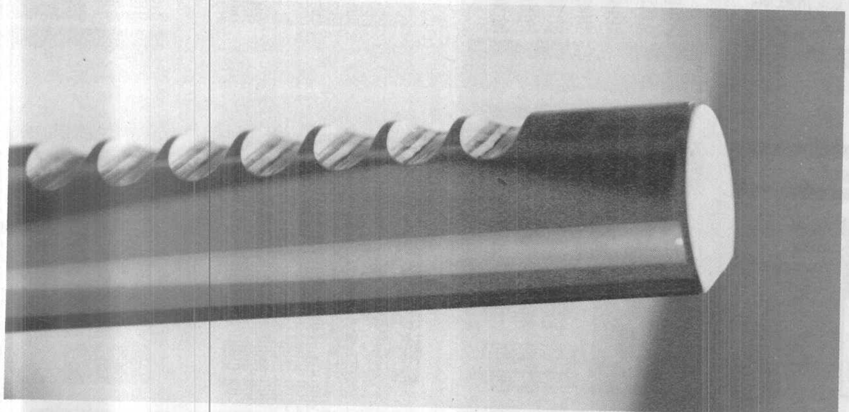

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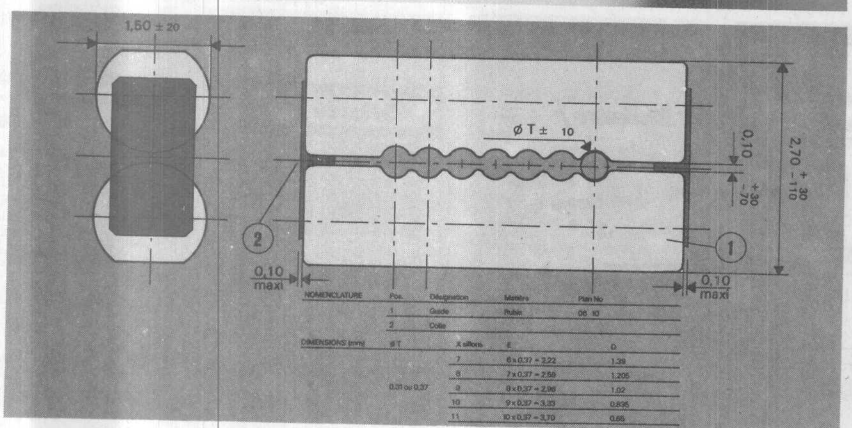

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		10	9×0,37 = 3,33	0,835
		11	10×0,37 = 3,70	0,65

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HAROLD ALDEN WHEELER

"I was born in the year that the Wright Brothers lifted off the ground at Kitty Hawk," says Harold Wheeler. "That was two years after Marconi sent a radio signal across the Atlantic. Those events colored my learning years and destined me to pursue one of those avenues. . . . In the seventh grade I elected radio, and I never swerved from that course."

He began early—the accompanying picture taken by his father in late 1920 shows him at 17 operating his homemade ham radio set. Soon after he met Alan Hazeltine, already a pioneer in radio receiver design: "He became my mentor; I was his understudy."

The understudy, still in college, was the first employee of Hazeltine Corp. in 1924, beginning an association that lasts to this day. In the ensuing 55 years, Wheeler has made major contributions to radio and television receiver design and to microwave, radar, and antenna design. In fact, the mention of his name to a microwave engineer is likely to bring a response such as "Harold Wheeler! I was just reading a paper by him the other day."

In the early days, Hazeltine Corp. was perfecting patentable innovations in receiver design that it then licensed, often designing the units for the licensee. The starting point was Alan Hazeltine's neutralized radio-frequency amplifier, the basis for the Neutrodyne radio that dominated the market in the mid-1920s.

Working independently, the teen-aged Wheeler had also dreamed up the Neutrodyne circuitry. He did not know of Hazeltine's work—still quietly making its way through the patenting process—and the parallel developments were a surprise to both at their first meeting. Hazeltine got the patent, but he granted royalties to Wheeler, as well as taking him under his wing.

Meanwhile, Wheeler was hard at work, obtaining the first BS in physics awarded by George Washington University and then taking graduate courses at Johns Hopkins University. Summers and spare time were spent at the corporation's first laboratory on the grounds of Stevens Institute of Technology or in his own lab in the basement of his parents' Washington, D. C., home.

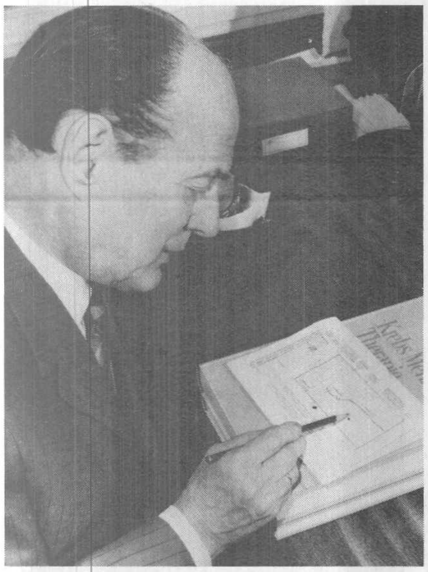
It was at home during the Christmas vacation of 1925 that Wheeler came up with the first practical circuit for automatic volume control on receivers. It was a marvel of simple design, because a single triode electron tube was connected as a diode for detecting the signal and for developing the bias voltage controlling the amplification.

"I really didn't appreciate how good it was," says its inventor. "That came on gradually." For years, his invention served as the principal source of income for the corporation. Now known as automatic gain control, the basic circuit is still in use today, notably in a-m radios and TV picture amplifiers.

In the 1930s, television receiver design was the prime object of Wheeler's attention. Then heading Hazeltine's research lab in Bayside, N. Y., he was on his way toward garnering his present total of 180 patents. Among the many awards he also received over the years, the 1940 Morris Liebmann Memorial Prize from the Institute of Radio Engineers for his TV work is particularly dear to his heart.

The World War II years for the corporation were devoted to military electronics, notably radar development. They also marked a turn to microwave and antenna research that continues to occupy him today.

In 1946, he left to form his own firm, Wheeler Laboratories, which did consulting research in communications. Hazeltine bought the labs in 1959, merging them into the parent research group in 1971. The purchase marked a new phase in Wheeler's career, for he served Hazeltine as chief executive officer in 1965–67 and as chairman of the board of directors from 1965 to 1977. He is still a board member and holds the title of chief scientist at the Greenlawn, N. Y., labs.

MANFRED VON ARDENNE

"Make your dreams come true." That's the advice one of Germany's most creative electronics pioneers has for young people aspiring to make a mark on science and technology. For Hamburg-born Manfred von Ardenne, now 73 and since 1955 head of his own research institute in Dresden, East Germany, it has always been the goal of his own technical—and lately medical—efforts.

Fascinated as a youngster by celestial and optical phenomena, von Ardenne soon zeroed in on radio, filing his first patent ("a method for achieving audio-frequency selection, particularly for the purpose of wireless telegraphy") in 1923 at the age of 16. Some 600 more patents as well as nearly 500 published papers and 20 books were to follow. The income derived from the publications and the sale of his developments allowed von Ardenne to finance his private laboratories in Berlin, where his parents had moved just before World War I.

Major inventions in the mid-1920s were the RC-coupled amplifier and a low-distortion tube incorporating three amplifier stages. This multiplexed tube—"in a sense the first integrated circuit," von Ardenne notes—helped cut a third off the price of radios with transformer-coupled amplifiers. Another feat was a 1-megahertz broadband amplifier housing two stages in one tube and using a low-capacitance, gain-boosting design. But it won widespread recognition only many years later when television, radar, and broadband communications came into being.

Not everything went smoothly, however. In 1930, von Ardenne proposed a cable radio broadcasting system analogous to community antenna TV but failed to win industry support for it. Annoyed, he turned to television, "a development whose merits the people and not just industry leaders could assess." Recognizing that the limited-brightness mechanical methods TV specialists were working on in the late 1920s were a dead end, he concentrated on electronic techniques from the beginning. That work culminated in a system using a flying-spot scanner at the pickup end and a cathode-ray tube at the receiving end. Von Ardenne made this purely electronic system work on Dec. 14, 1930, at his Berlin labs.

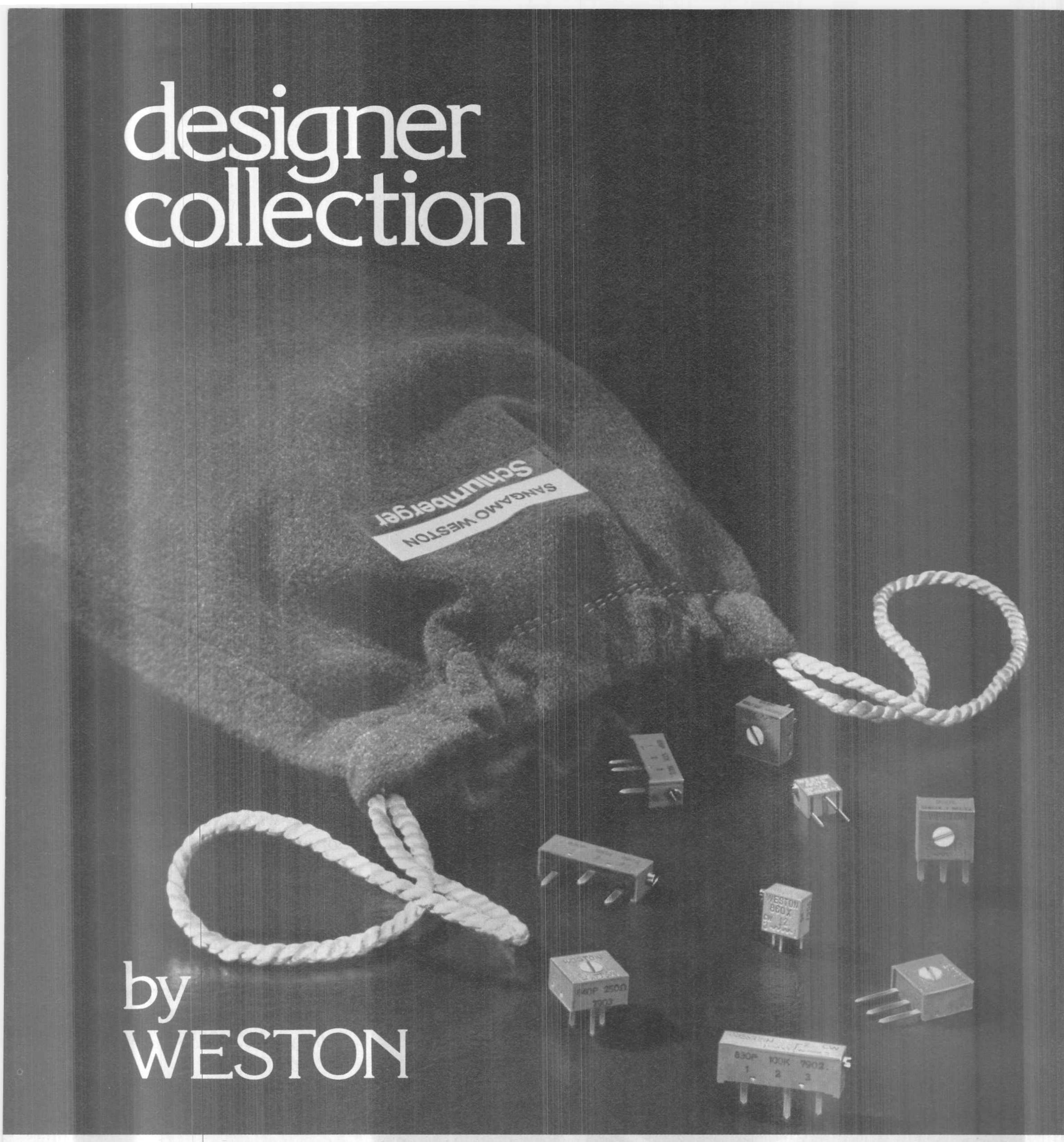
To give his experimentation a scientific underpinning, von Ardenne studied for four semesters at Berlin University, though he did not earn a degree. In those days, "it was largely an experimenter's realm, a world marked by trial and error," he reminisces. Since a lot of instruments were unavailable, "we had to build them ourselves," he says. "We even had to blow the glass for our tubes." Not surprisingly, his Berlin labs had much equipment not found in today's lab.

After television, he turned to other areas of electron optics. Technical milestones from 1933 to 1937 were the development of a projection electron-beam oscillograph, the invention of the electron-optical image converter, and the development of broadband oscillograph amplifiers (from 0.2 hertz to 3×10^7 Hz), the polar-coordinate electron-beam oscillograph, and the scanning electron microscope with beam diameters down to 10 nanometers.

The World War II years were marked by such achievements as improvements in scanning electron-beam methods and were followed by a period in the Soviet Union in charge of a research institute. Then in 1955, he returned to what by then had become East Germany to head "probably the only private institute in our part of the world," he says. His and his co-workers' major electronic feat in Dresden was the development, in 1959, of an electron-beam multichamber furnace for melting heavy blocks of metal in a high vacuum.

Did von Ardenne foresee the importance of his work at the time? "Generally yes," he admits, though he is a beguilingly modest man. "For example, I recognized the significance that the cathode-ray tube would eventually have in oscillograph technology." Some developments, whose importance was not immediately obvious to the German industry, were first perfected abroad. A case in point is the scanning electron microscope.

Like some other electronics pioneers—Zworykin, for one—von Ardenne turned to medicine, specifically to cancer research and therapy, a field which has engaged him since 1959. "I wanted to become active in an area with still many unsolved problems," he says.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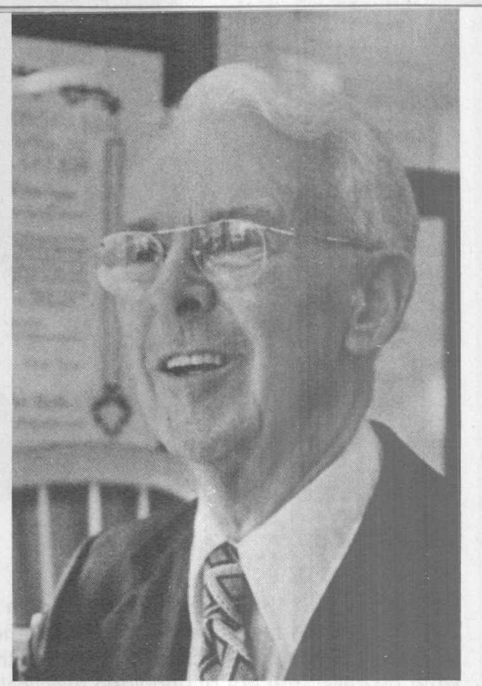


HAROLD S. BLACK

If Harold S. Black had stayed angry at not receiving a raise in pay soon after starting work at Western Electric Co.'s laboratories—he later went to Bell Laboratories—someone else would probably have had to invent the negative feedback circuit, a development recognized as one of the landmarks in communications.

Black had launched his career at Western fresh out of Worcester (Mass.) Polytechnic Institute. The date was July 5, 1921, and the lab was located near Manhattan's West Side docks, at 463 West Street. He rode the ferry each day from New Jersey, and it was while commuting on Aug. 2, 1927, that the feedback idea came to him 'in a flash.'' Black drew the circuit diagram and some mathematical notations on his New York Times, showed it to his fellow scientists when he got to the lab, and a basic problem of long-distance communication—noise—was solved. Black's interest in the noise problem was long-standing: he had previously worked on reducing hum in phone lines and then on the modification of push-pull amplifiers.

That missing pay increase had almost sent an angered Black to Harvard's business school. But he changed his mind and decided on a different course. "Every memo, written idea, or lab note from the first day of the lab in 1898 had been preserved. So I got them from the library and started coming in on Sundays to read them all. I also found out where all the well-known researchers worked and got to know them," he says. In short, Black became an expert on all the work that had gone on at Western Electric.

Another source of inspiration to the young Black was Charles Steinmetz, the wizard of General Electric. In fact, a lecture by Steinmetz in 1923 led to another Black development: the feed-forward amplifier, also a basic communications breakthrough. In all, Black holds 333 patents—62 in the United States, 271 granted by 32 foreign nations.

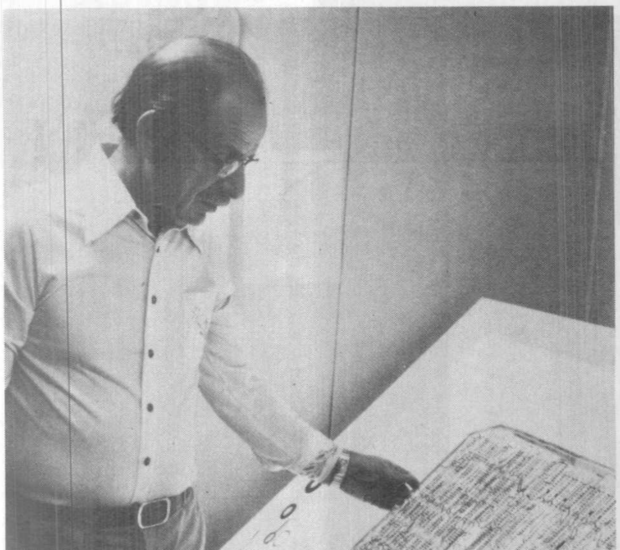
But Black, 82 years old, is excited most by the developmental work that is going on today in communications. "They are moving ahead at an exponential rate," he says. Then, eyes flashing, he says, "I predicted that and helped make it happen."

The key to it all, of course, is digital communications. "In World War II," he recalls, "systems started to be converted partially to digital from all-analog. And I helped make it happen when I was the first one in this country to use pulse-code modulation."

What fascinates Black most about today's digital communications technology is fiber optics. "Its potential is enormous," he says. He compares the improvement still to come with the evolution from his first feedback amplifier and those in use today. "My first one was 19 by 9 by 10 inches," he says. "Now they can get 18,000 feedback transistors in an area about the size of a paper clip."

Black looks back at his Bell Labs years fondly, except for the fact that "they fired me" through the retirement-at-65 rule. So he went to General Precision Inc.—now the Kearfott division—in Little Falls, N. J., as principal research scientist for three years, then did some consulting at Dr. Howard Rusk's New York Hospital for Rehabilitation Medicine by serving on biodmedicine and biomedical engineering committees. Today, the still-sprightly scientist does some consulting work from his 30-year-old home perched gracefully on a hill in Summit, N. J., not too far from Bell Labs in Murray Hill.

"I still drop in there once in a while," he smiles. "I can't get over the things they're doing now, especially when I recall I was told not to worry about designing nine-channel systems because the most that Bell System operating companies would ever need was three."



ROYDEN C. SANDERS

Before Dec. 18, 1950, the safest place on a test range was supposed to be the target. Royden C. Sanders (63 years old this April) can take credit for leading the Navy out of what he calls "the era of unguided missiles" on that date, when a Raytheon Lark scored the first direct hit by a U. S. guided missile on an aircraft in flight.

During 1937–38 Sanders, who had quit college to go into electronics full time, worked on what would become the first practical fm radar altimeter. The Radio Corporation of America invited him to work on the system in its New Jersey laboratories, and eventually—during and after World War II—half a dozen firms turned out more than 300,000 of the devices. The basic design was also modified for use as a radar bombsight.

That was Sanders' first entry into the business, and he had a great future ahead at RCA. He nevertheless left in 1944 because he felt the firm was beginning to divert resources away from the war effort. "I wasn't sure we were going to win that early in the game," he recalls. (RCA was sure, though—it was planning for the postwar boom in television.)

Sanders went to the Raytheon Co. as part of a group that later became the Missile and Surface Radar division; Sanders headed the group, originally known as Lab 16—"because there were 15 others." One of Lab 16's first efforts, missile guidance, continued even after the war.

In 1944, the Navy needed a defense against Japanese kamikaze attacks; out of this requirement came the Lark missile and its successors, the Sparrow III and the Hawk. The original Lark was to have had an active radar guidance system; it might have been the original "fire and forget" missile. But the Navy wanted a longer-range system, where a powerful airborne radar illuminates the target and the missile passively homes in on the reflections. So the design was changed—but not before one of Sanders' Larks scored its direct hit.

Sanders says it scored largely because of his insistance on burning-in each missile's electronics for 24 hours before firing it. He recalls the bemused response of his fellow engineers to the thought of using an entire day's burn-in to assure dependability during a flight measured in minutes—now a standard reliability technique.

As part of his missile work, Sanders also studied high-density electronic packaging. To offset tube-related thermal problems, he used the missile's skin as a heat sink.

In 1951, feeling that "I had started up two good businesses for other people," Sanders figured it was time to start his own. He and 11 others from Lab 16 mortgaged their homes, pooled resources, and began bootstrapping Sanders Associates into existance.

The company's first contracts were for missile system consulting, so-called Tinkertoy electronic modules, electronic countermeasures (EMC) equipment, electronic intelligence gathering (Elint) gear, and sonar. Sanders' ECM gear is said to have been the first to use an adaptive, broadband repeater approach; formerly ECM had consisted of simple-minded jammers.

Sanders' ECM, Elint, and sonar work led to other efforts in signal and data processing. These resulted in the formation of the Sanders Data System division—a major profit center before his departure in the mid-1970s—which in turn led to Sanders' present interest in work on the office of the future.

This interest is reflected in the goals of his present firm, R. C. Sanders Technology Inc. Sanders views the information explosion both as inevitable and as survivable—with the necessary aids: intelligent printers, display consoles, and word-processing and data-base management equipment. And he has therefore placed his new firm squarely in that market.

Sanders remains concerned with technology, both for personal reasons—"If I don't get to work at the bench once or twice a month, I get edgy"—and out of patriotism: "Today, commercial technology is developing far more rapidly than military. I'm concerned that unless we push military technology development, we risk the survival of the nation." He places the blame for this lag on "woefully inadequate Federal leadership."

Meanwhile, he puts in long hours at Sanders Technology. "We expect to be in the black in 1980," he says, and as for retirement, "my wife says I'll be a retiree when I get my work week down to 40 hours."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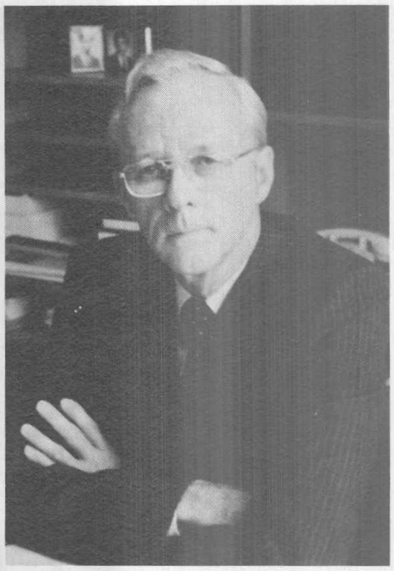


JAY W. FORRESTER

At age 62, Jay W. Forrester has not only played a major role in the creation of computer technology, he has also applied it in dramatic fashion in recent years as Germeshausen Professor of Management at the MIT Sloan School of Management.

Forrester was director of MIT's digital computer laboratory from 1946 to 1951, responsible for the design and construction of the Whirlwind I, one of the first high-speed digital computers. From 1952 to 1956, he headed the Digital Computer division of the MIT Lincoln Laboratory, guiding and planning the technical design of the Air Force's Sage (for semiautomatic ground environment) air defense system, the most extensive early application of digital computers—and one that might not have been possible in terms of either speed or reliability without his invention of the magnetic-core memory.

Whirlwind was developed using electrostatic storage tubes as memory; experimenters were working with several types of delay lines and with other tube techniques. But these various memory technologies were either slow or unreliable. Forrester had been working on the memory problem since at least 1947. So when in 1949 he happened upon an advertisement for nonlinear magnetic materials, the pieces of the puzzle fell into place. In a few days he had obtained material and had established proof of the principle of the coincident-current magnetic-core memory, laying the groundwork for the memories that were to emerge from development about four years later.

In 1956, Forrester decided to change careers. Though he is still honored for his pioneering computer work, he has beome the leading theoretician in the field of complex socioeconomic models—system dynamics.

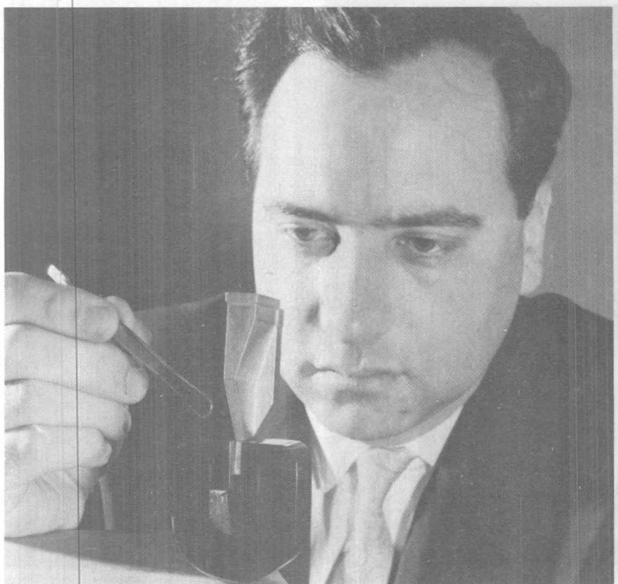
Forrester notes that his responsibilities at Sage were as much managerial as technical. He came away from them convinced that "technical success could depend more on management than on science" and that "no amount of technical expertise could surmount an unfavorable managerial environment."

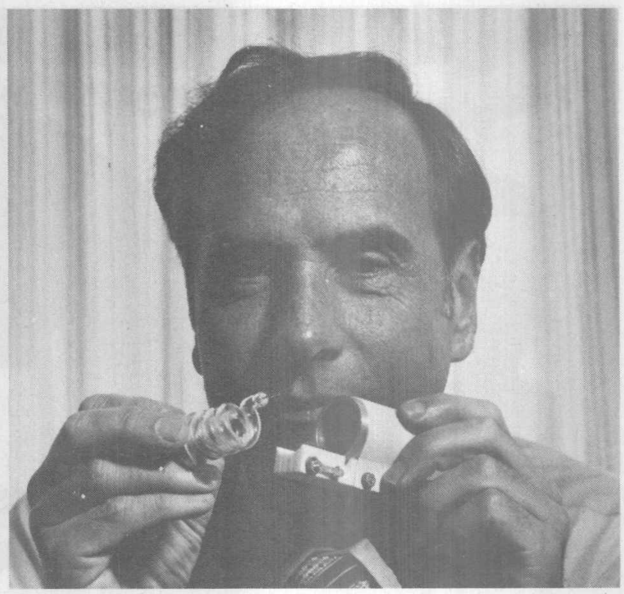
With this belief and the feeling that "management was the greater challenge," he moved to MIT's Sloan School in July 1956. Forrester explains that the Sloan School had naturally taken to the use of computers, especially for operations research and for management information processing. But neither of these was "the correct challenge," in his opinion. "Business data processing was already evolving rapidly outside MIT," he notes, "and operations research dealt with relatively simple problems, not with the keys to success or failure of major efforts."

He combined his thinking with input from managers, finding that executives were concerned with the ebb and flow of capital, fluctuations in inventory, unemployment, and inflation. These and other seemingly cyclic occurrences reminded Forrester-the-engineer of oscillations, and he wondered if, through modeling their environments, he might not be able to find a way to apply "negative feedback" to control them. And what better tool for developing such models than the digital computer, which he also had helped develop. He thus midwifed a new field of study, system dynamics, or "how . . . policies affect growth, stability, fluctuation, and changing behavior in corporations, cities, and nations."

As his confidence in his models grew, Forrester began speaking out on a variety of issues, most recently innovation, the energy shortage, and long-wave economic cycles—a controversial phenomenon independently predicted by his computer models. He has targeted a number of policies he feels should be pursued. In energy, for example, he would alter price stuctures so that industry would be forced away from energy-intensive processes.

One of system dynamics' key insights is that the obvious course of action is rarely the correct one; that, in fact, a "logical" course of action can have the reverse of the desired result. Based on the behavior of his models, Forrester often therefore finds himself advocating "counerintuitive" solutions to problems. The moral for social and economic planners is obvious—make it play on the computer first. While no one could call Forrester's pioneering work in data processing unimportant, the potential of system dynamics is so great that it may someday overshadow his engineering achievements.





THEODORE H. MAIMAN

If oddsmakers 20 years ago had handicapped Theodore H. Maiman's chances of coming up first with a working laser, he would have been a long shot. "But I knew something the others didn't," he recalls now about the months preceding May 15, 1960.

Maiman's advantage lay in his knowledge and experience of ruby as lasing material for a coherent light source. He began working with it back in graduate school days in the mid-1950s at Stanford University. He found then and in subsequent R&D projects at Hughes Aircraft Corp. that ruby has much higher fluorescent efficiency—around 75%—than the accepted textbook 1% or so limit. This property is critical to lasing action and meant Maiman could focus his effort—his one assistant and a limited budget—on building a ruby laser. He did not lack confidence: "Once I had the idea, I knew we had the inside track," he says now.

Maiman was bucking the judgment of well-financed programs at some of the most prestigious research firms and institutions in the U. S. and Europe. "There was a worldwide race to make the laser," he points out.

But by the time he had permission from Hughes management to start in August 1959, other scientists were up against a stone wall in building a working model. They based most of their work on a landmark 1958 paper by A. L. Schawlow and C. H. Townes that proposed an optical maser, but one that used a potassium vapor to generate coherent light rather than a solid material.

"I had built an X-band maser in 1958–59 for the Army Signal Corps, which depended on the microwave characteristics of ruby to work," he explains. Already intrigued with the material's optical possibilities, he set about constructing a laser with it, after first looking into the Schawlow-Townes theory and satisfying himself that "it would not work."

Maiman's background turned out to be particularly well suited to implementing the laser. He was familiar with optical energy and instrumentation from his doctoral thesis at Stanford on microwave-optical measurements and from work in generating electron beams. And at Hughes Research Laboratories, where he headed the quantum electronics section, Maiman already had developed new masers that were coded with liquid helium and liquid nitrogen.

Lending further impetus to his laser experiment was a Hughes management mandate to do it quickly. "Hughes never really thought much of the laser," he says, and almost withdrew funding on advice from Bell Lab consultants. But the nine-month program went smoothly, and the first demonstration was successful.

There were skeptics at first, but now "nobody challenges the fact I made the first laser," observes the 52-year-old scientist. But some confusion, prevailing even today, still rankles. Townes, for example, shared a Nobel Prize in 1964 for theoretical work leading to the maser and laser. Maiman's stock reply to any who try to take credit for his development: "If they did it, where the hell is their laser?" Often he punctuates speeches and appearances by whipping the first laser itself out of his pocket.

In 1961, Maiman left Hughes to set up his own industrial laser company, Korad Corp., sold to Union Carbide in 1968. Since then, serving as a consultant to top industrial firms, he has been "out of the active laser field." But he did aid in developing a large-screen laser-driven color video display.

Maiman joined TRW Electronics in 1976, where today he ranges far afield as vice president of advanced technology. There, among duties like helping guide the company into new ventures, he brought TRW's LSI Products division into the commercial world from a lab beginning.

Contemplating the 20 years since his laser first generated a coherent light beam, he takes strong issue with negative judgments to the effect that the device was "a solution looking for a problem." He had always foreseen industrial uses for the laser and not the flashy communications systems some visionaries predicted right away. "These are just now starting to pick up, which is where they should be."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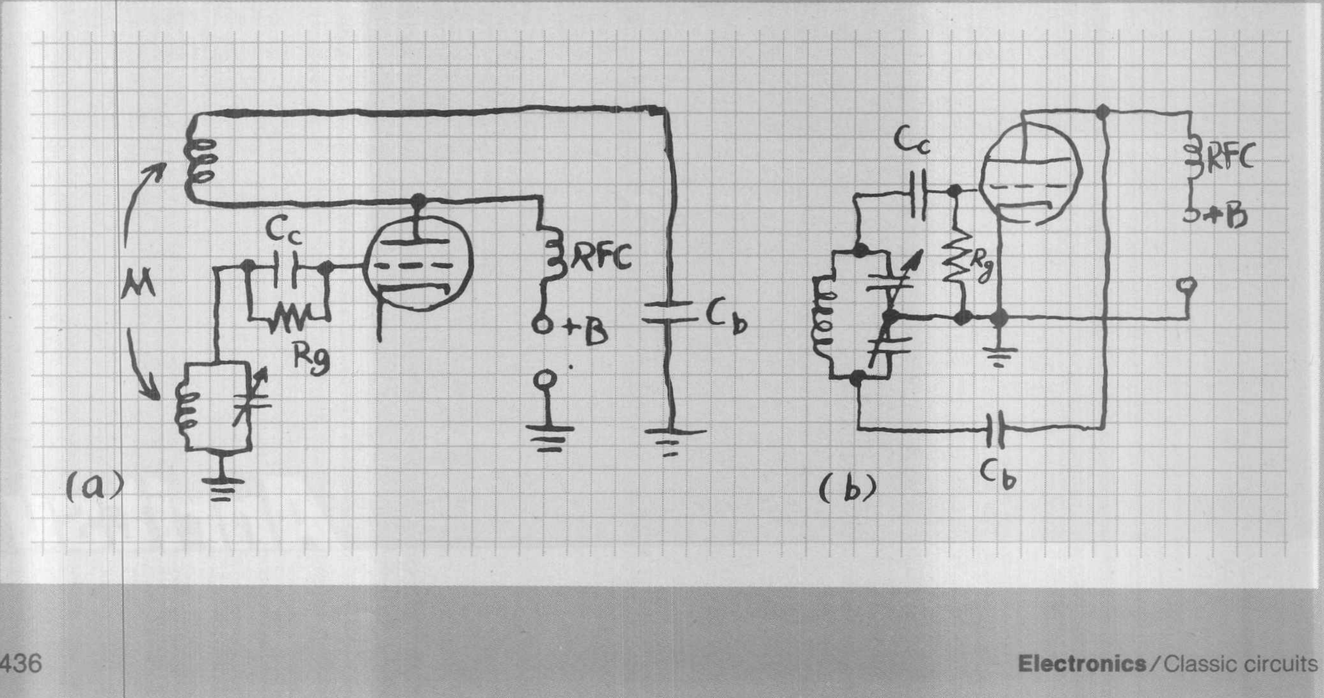
CLASSIC CIRCUITS

The growth of electronics as a group of industries has resulted from a complex of factors—technical, social, economic, and political. But in the last reckoning, it has been the development of the circuits themselves that has made electronic communication and data processing possible.

Although there have been many innovations over the years, all circuits actually trace their roots back to only a dozen or so, from which all else was created. Presented here are some of the great circuits, those that *Electronics* feels have been basic to the commercialization of radio, TV, and computers and other data-handling systems. The selection has been difficult, and others indeed might have been chosen, but *Electronics* believes that these truly innovative circuit designs would occupy a spot in just about everyone's all-star list.

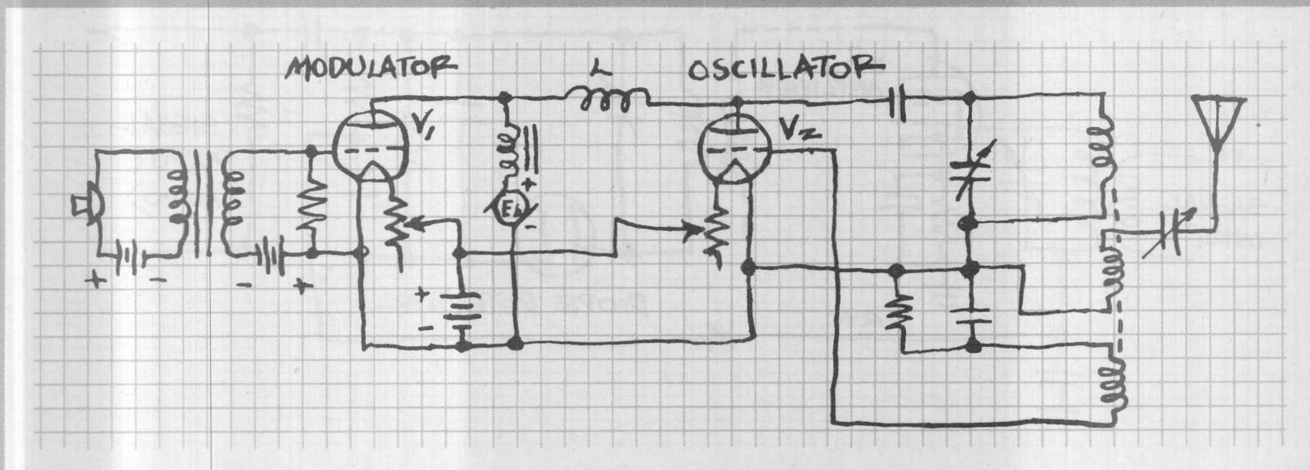
1. VACUUM-TUBE OSCILLATOR: c. 1912

The vacuum-tube oscillator generated continuous waves at a single frequency, unlike its predecessor, the spark gap, thus permitting communication over a single channel. Using positive feedback and the triode as an energy pump, it provided a sine-wave output at the resonant frequency of its tuned circuit. Several individuals invented the circuit in about 1912 independently, notably Reginald A. Fessenden, Alexander Meissner, H. J. Round, and Lee de Forest, but the arrangements by Edwin H. Armstrong (a) and Edwin Colpitts (b)—a similar circuit was devised by R. V. L. Hartley—were used most widely in the early going.



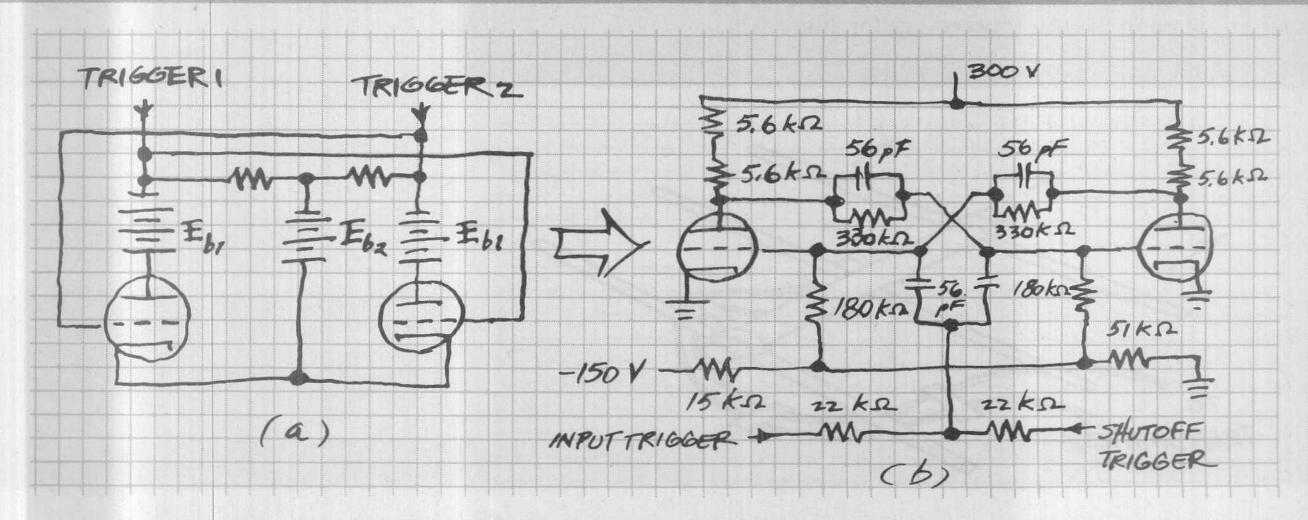
2. CONSTANT-CURRENT MODULATOR: 1913

R. A. Heising's vacuum-tube circuit, initially conceived at Western Electric in 1913, was the first modulator capable of working efficiently. With inductor L preventing any change in the total plate current drawn by V_1 and V_2, the modulating signal was applied to the plate circuit of the rf oscillator so that audio-frequency variations at the modulator's output would produce similar variations in the oscillator's plate current.



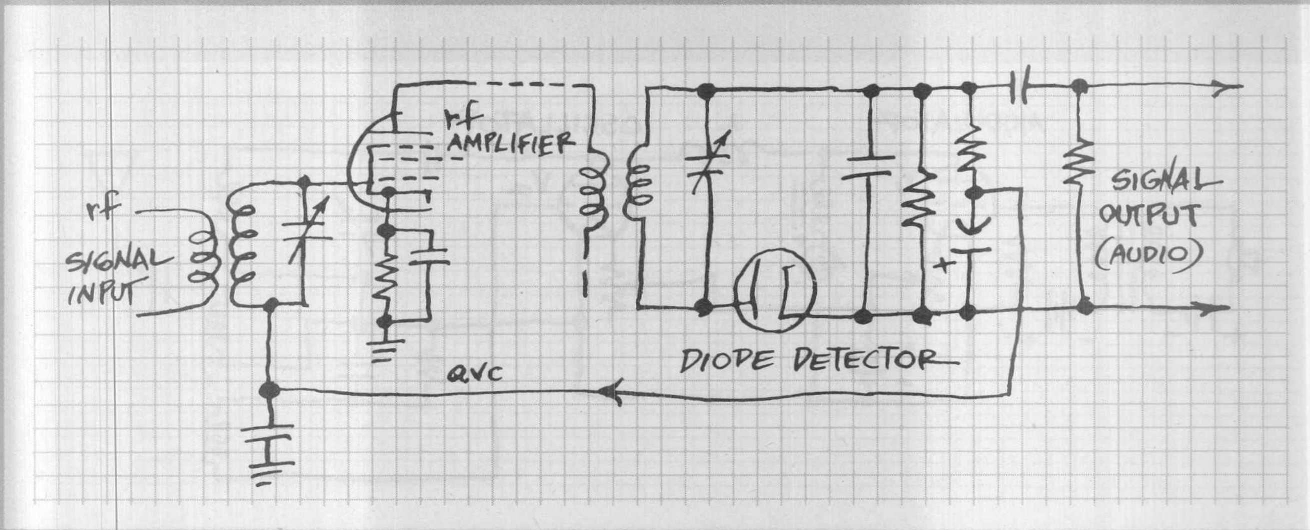
3. FLIP-FLOP: 1919

Among the many circuits derived from the general trigger arrangement (a) invented by W. H. Eccles and F. W. Jordan, working in the UK, were the monostable and astable multivibrators and the Schmitt trigger. The bistable latch, or flip-flop (b), is the ancestor of the frequency counter-divider and the computer.



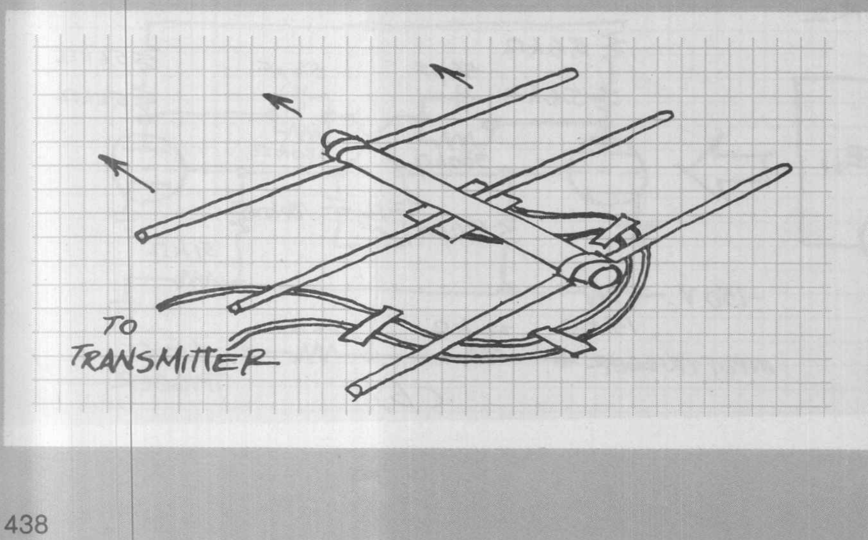
4. AUTOMATIC VOLUME CONTROL: 1926

One of the first circuits to utilize the properties of negative feedback, Harold A. Wheeler's automatic gain control for a-m radios provided a substantially constant audio output volume over a wide range of rf signal levels. Wheeler designed the AGC in 1926 at Hazeltine Corp., where he works to this day.

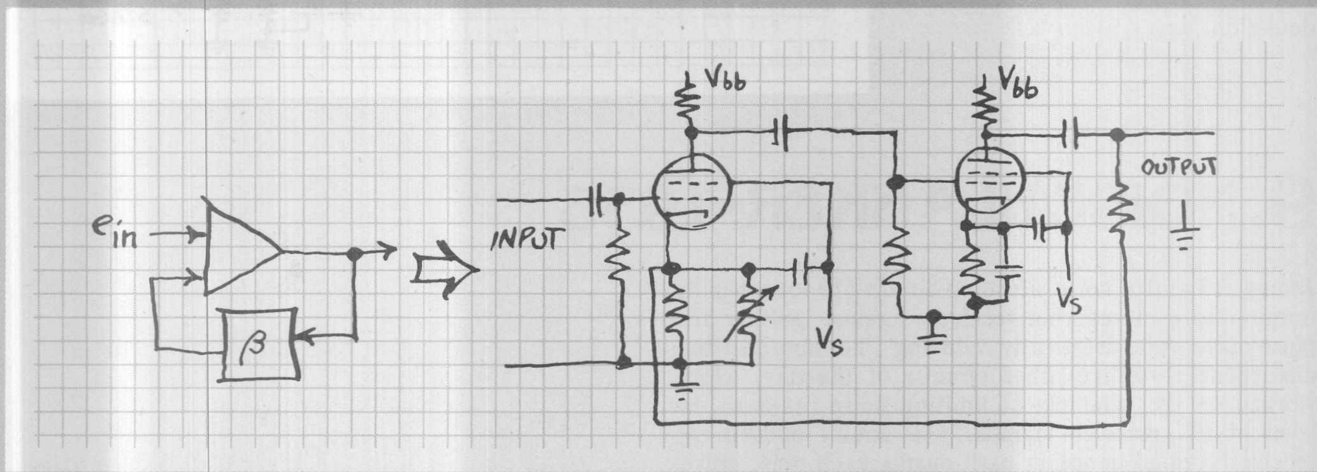


5. YAGI-UDA ANTENNA: 1926

Developers of a different kind of circuit—an electromagnetically coupled one having large dimensions compared with the wavelength of interest—H. Yagi and S. Uda of Tohoku University, Japan, were the first to use wave interference to obtain gain and directivity from wire aerials. Although the invention was conceived in 1921, the commercialization of their discovery took place in the West in the late 1920s, after a translation of their paper appeared in the IRE Proceedings for June 1928.

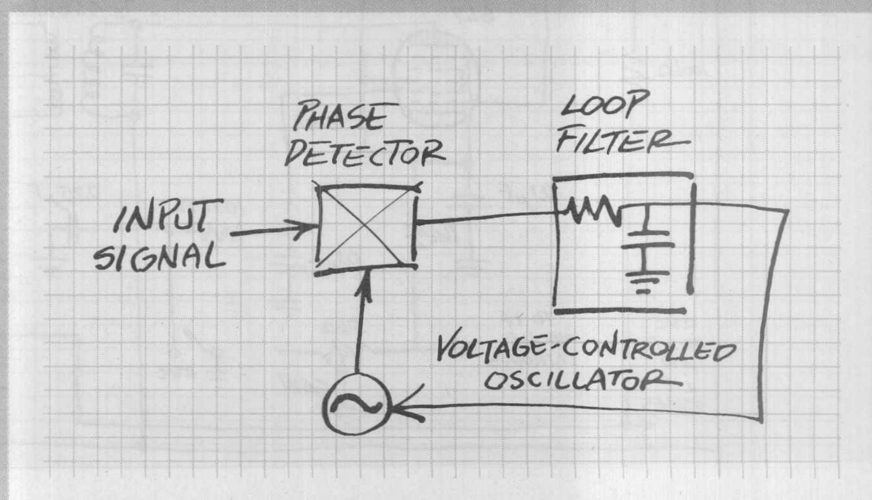


In one of the most fundamental developments in the history of communications, H. S. Black discovered that negative feedback could be applied to an amplifier to minimize distortion over a wide band of frequencies and achieve gain stabilization at the same time. This work, performed at Bell Telephone Laboratories in 1927, was different from that of Wheeler, who had earlier used negative feedback for control.



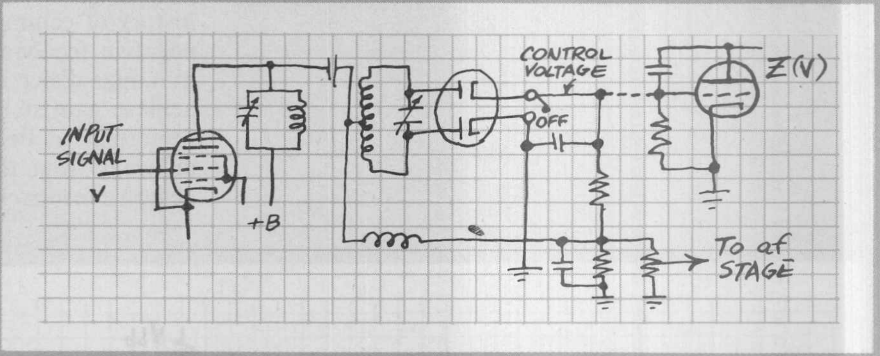
7. PHASE-LOCKED LOOP: 1932

H. de Bellescize, working in France, was the first to describe a system for the synchronous reception of radio signals, one that was simpler and more elegant than the superheterodyne approach then used. Using a feedback control loop to adjust a voltage-controlled oscillator to the exact frequency of an incoming signal, the PLL, originated in 1932, is employed widely in many data-processing and communications circuits today.



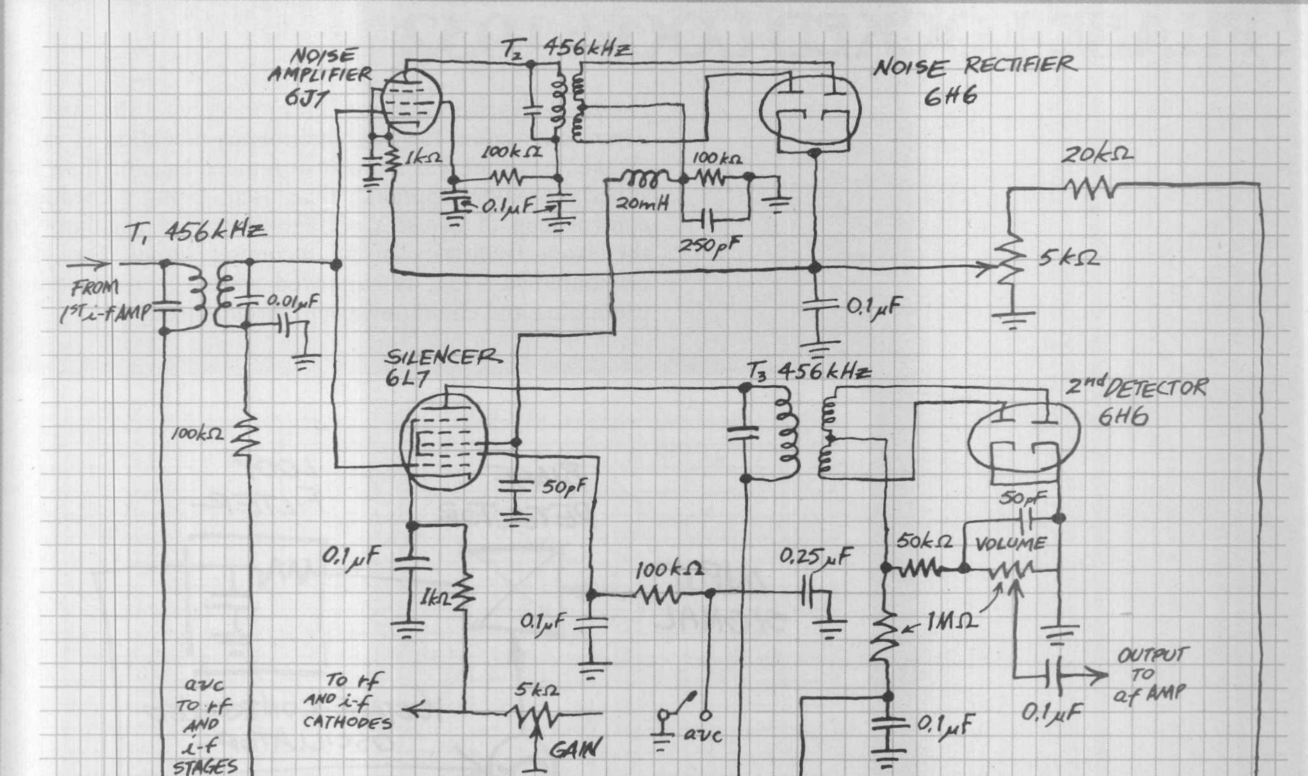
8. AUTOMATIC FREQUENCY CONTROL: 1935

Charles Travis's discriminator and reactance-tube circuit (shown here in a modified simplified version by S. W. Seeley), developed in 1935 while he was at RCA, formed the heart of the first automatic frequency control and was the basis of the reactance-tube modulator and the Foster-Seeley discriminator for fm detection.



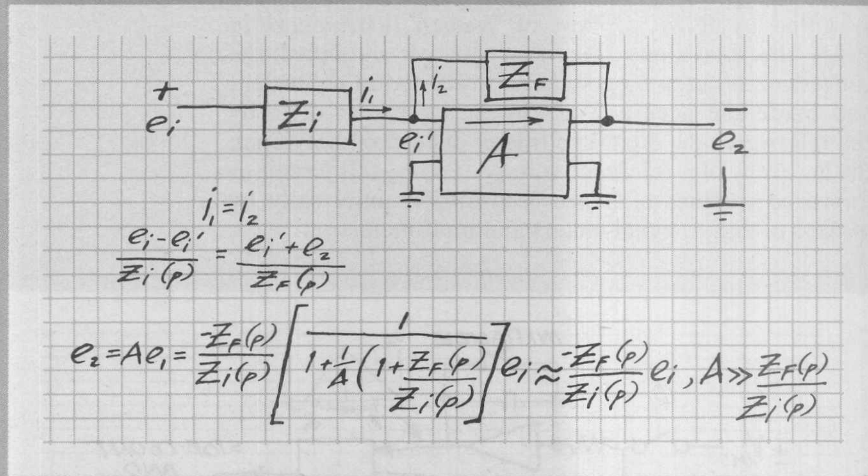
9. NOISE BLANKER: 1936

James J. Lamb's noise-silencing circuit (1936) virtually immunized a-m superhet receivers against ignition and pulse noise while drastically reducing other nonrepetitive disturbances—unlike other circuits of the day, which worked on the principle of limiting noise peaks to the level of the received signals. The circuit opened the receiver's signal-handling path during each noise spike, allowing the desired signal through at other times.



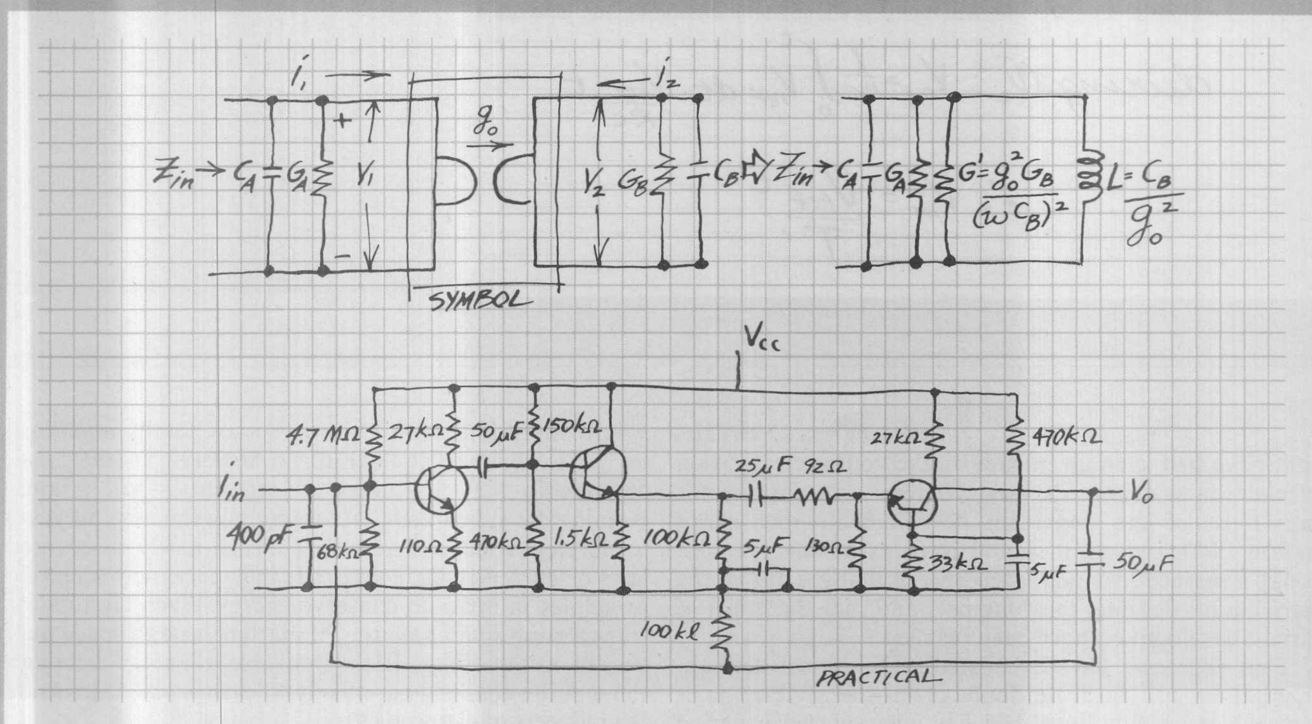
10. OPERATIONAL AMPLIFIER: 1938

The discovery by G. A. Philbrick in 1938 of the operational amplifier for performing integration and differentiation by electronic means was not so much the invention of a circuit as it was the development of a concept. Using an odd number of ordinary high-gain vacuum-tube stages for generating the required 180° phase shift between input and output, Philbrick (also, independently, C. A. Lovell) showed that the transfer function of the network could be set with two external elements. This work led to the development of the active filter.



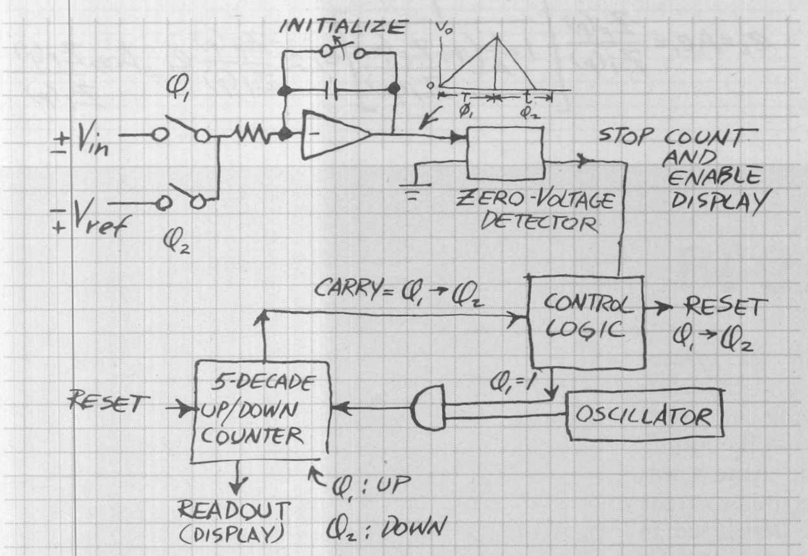
11. GYRATOR: 1948

B. D. H. Tellegen's invention in 1948 of the gyrator made unidirectional microwave couplers and inductorless electric-wave filters possible. Having an input impedance proportional to the admittance at its output, this almost lossless nonreciprocal network element was thus able, given a capacitive load, to synthesize the electrical characteristics of an inductor. Developed in 1948 at Philips, this element appears passive, though most configurations contain active components.



12. DUAL-SLOPE INTEGRATOR: 1955

Invented by R. W. Gilbert of Weston Instruments in 1955, the dual-slope integrator greatly simplified the conversion of an analog signal into its digital equivalent and made the accuracy of any measurement done by the relatively new digital voltmeter dependent only upon the accuracy of a reference voltage. Today, this circuit or improved versions of it are used almost universally by makers of digital panel meters and multimeters.



$$\text{during } \phi_1 : V_{o\uparrow} = \frac{1}{RC}\int_0^T V_{in}\,dt = \frac{V_{in}}{RC}T$$

$$\text{during } \phi_2 : V_{o\downarrow} = \frac{1}{RC}\int_0^t V_{ref}\,dt = \frac{V_{ref}}{RC}t$$

$$\therefore V_{in} = \frac{V_{ref}\,t}{T}$$

In saluting the 12 circuits that have had such an impact on the commercialization of electronics during the past 50 years, one fact stands out: most of the important developments took place before 1940. Indeed, it should come as no surprise that today's engineers by and large believe that the day of the pure circuit designer has long past and that the limits of circuit development have been reached.

That engineers have exhausted conventional development there can be little doubt. The first generation is virtually over. But the world has now entered a period where diminishing natural resources are vitally important to the survival of industrialized society. To that end, engineers—that is, ones of *ingenuity*—will almost certainly be called upon increasingly in the next 50 years to develop circuits that utilize either newly discovered laws or currently little-used but now necessary scientific principles in order to conserve energy. Even circuits for transporting small amounts of matter through space may well be in the offing. Those individuals inventive enough to meet the challenge are likely to earn a place alongside the pioneers of electronics.

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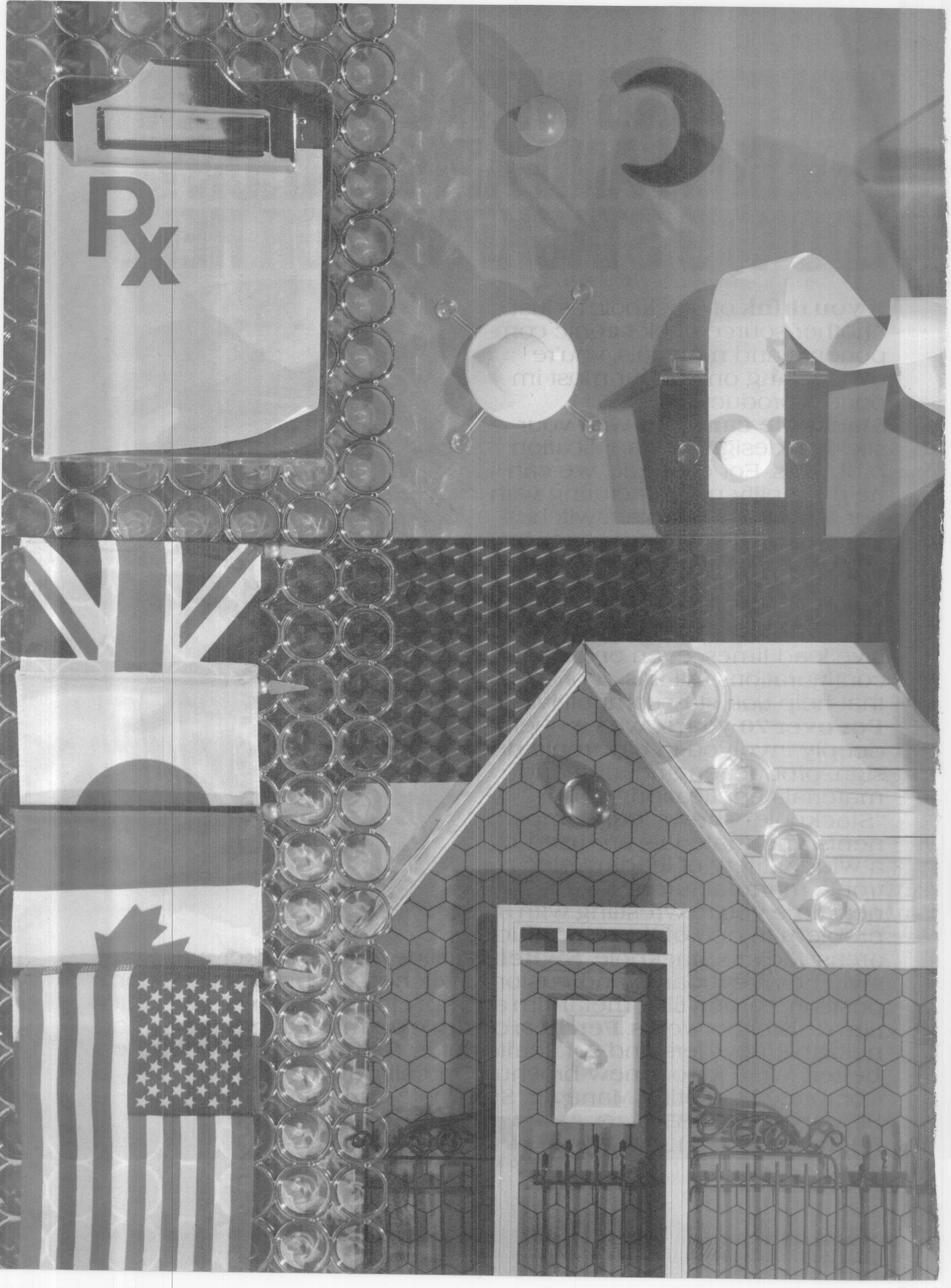
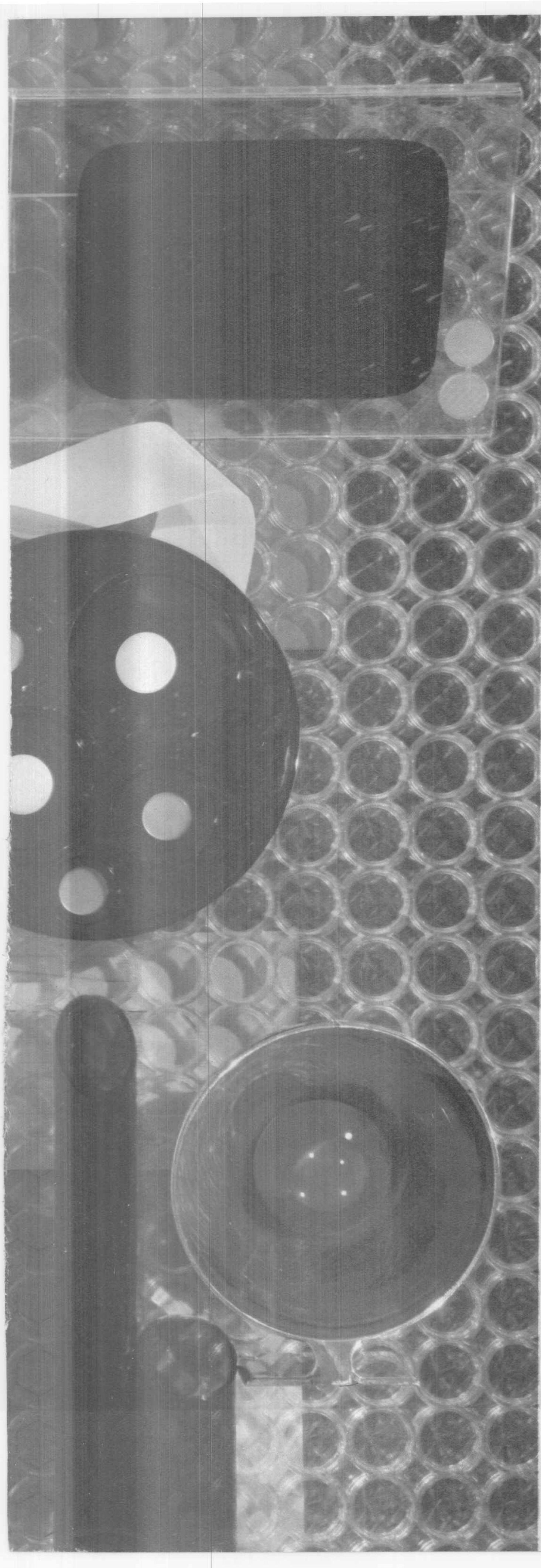
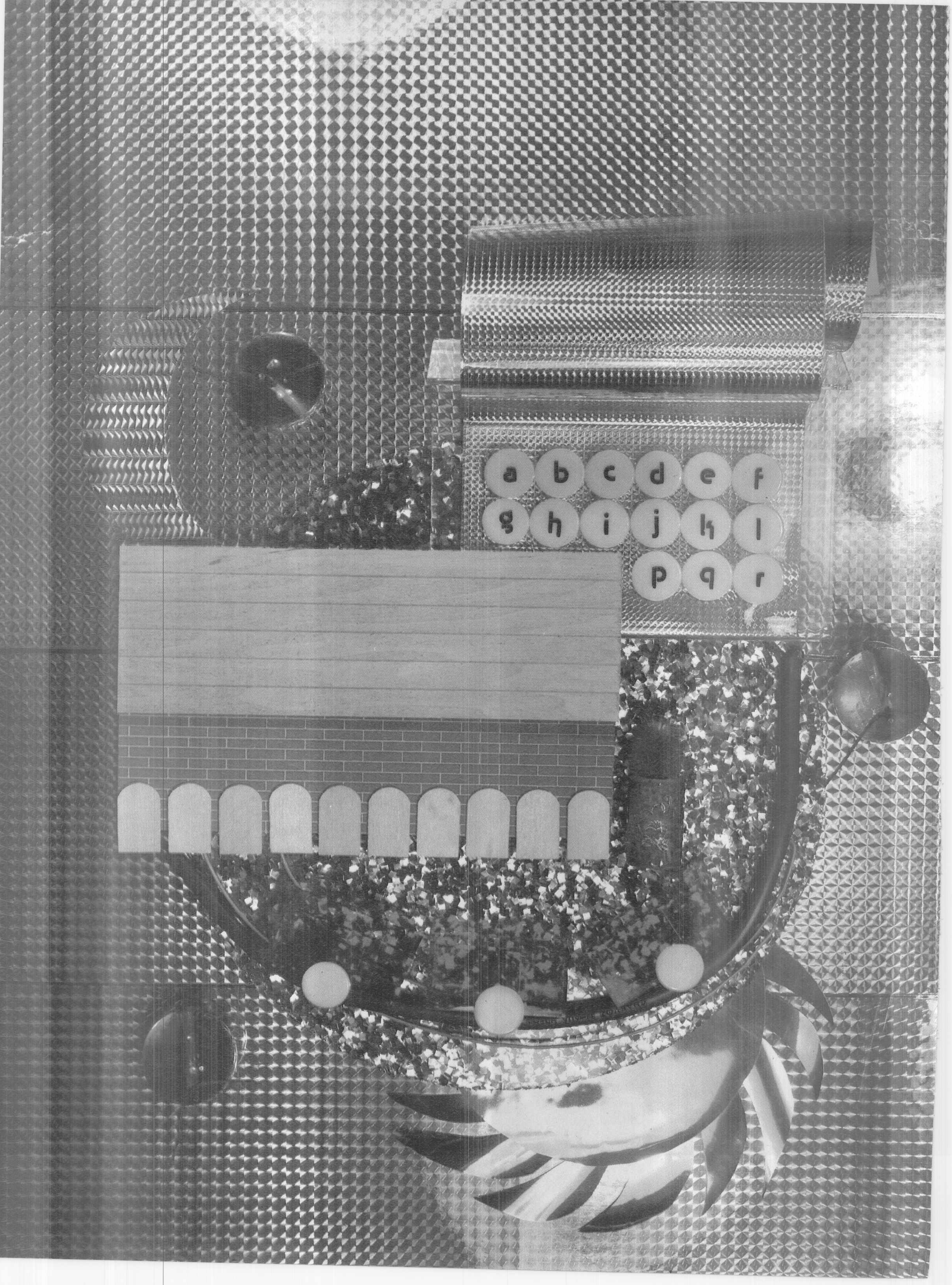

Rx



FUTURE

IF WHAT'S PAST IS PROLOGUE, THE FUTURE OF ELECTRONICS WILL BE ONE OF RAPID CHANGE—INNOVATION RIDING ON THE CREST OF TECHNOLOGY. IN THE NEXT 20 YEARS, SYSTEMS THAT REFINE THE RUNNING OF THE HOME, THE WORKPLACE, AND SOCIETY AT LARGE WILL TRANSFORM THE ROUTINES OF EVERYDAY LIFE. BUT FIRST THE LIMITS OF TODAY'S TECHNOLOGY MUST BE TRANSCENDED. AND AS THEY YIELD, THE ENGINEER'S CAREER WILL UNDERGO FORESEEABLE REVISIONS, AND THE ELECTRONICS INDUSTRIES COULD EXPERIENCE EXTENSIVE RESTRUCTURING.
IN SHORT, THE FUTURE PROMISES TO BE EVERY BIT AS EXCITING AS THE PAST.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SYSTEMS

THERE WILL BE INTELLIGENT ELECTRONIC SYSTEMS ALMOST EVERYWHERE—IN MOST HOMES, SCHOOLS, OFFICES, AND FACTORIES, IN HEALTH CARE CENTERS, DEFENSE ARSENALS, AND IN SPACE. THE GREAT DIGITAL TAKEOVER THAT BEGAN IN THE LAST DECADE WILL ACCELERATE IN THE NEXT TWO UNTIL, BY THE YEAR 2000, THE AVAILABILITY OF INEXPENSIVE COMPUTING POWER COUPLED WITH EXTENSIVE COMMUNICATIONS NETWORKS WILL HAVE WOVEN ELECTRONICS INEXTRICABLY INTO THE VERY FABRIC OF SOCIETY. FOR BETTER OR WORSE, THIS MARRIAGE OF COMPUTERS AND COMMUNICATIONS WILL EXPAND A PEOPLE'S CONTROL OVER ITS CIRCUMSTANCES IN A MYRIAD NEW DIRECTIONS.

The most significant coming trend in electronic technology will be the gradual merging of telecommunications and data processing, a meld that by the year 2000 will have profoundly affected many aspects of our daily lives.

There is not yet a generally accepted name in English for this development. But the French, precise in their language, have come up with a term—"télématique"—to suggest a marriage of telecommunications networks with data processing. Perhaps "information teleprocessing" will come to convey the idea of communicating and acting on knowledge from a distance.

Whatever its label, the process will have an enormous impact on the home and workplace. At the heart of this trend will be a combination of inexpensive computer power and ever increasing memory capacity provided by semiconductor technology.

Electronics in the form of dedicated intelligence will be everywhere—in home entertainment, appliances, automobiles, airports, highways, offices, banks, stores, factories, hospitals, schools, and, of course, in space. Prodigious strides have already been made along these lines, but the sheer volume of information processed, stored, and transmitted in the future will be mind-boggling.

The world, then, is entering what one industry researcher terms the "era of computational plenty." But to exploit this new wealth, further advances will have to be made.

One of the obvious requirements will be a means of rapidly extracting desired information from the massive amounts of data there will be on file in the proliferating processors. Thus there will be a need for systems that adapt to the user rather than responding only to programmers.

What steps will have to be taken in a society filled with machines that must "talk" to everyone? For one thing, very large-scale integration (VLSI) will lead to new devices designed specifically to exploit submicrometer spacing and reduce interconnections to maintain speed. Where a prime concern so far has been the reduction of active elements—integration—the emphasis in the future will be on reducing interconnections.

A second key area of development will be interface technology—getting data into and out of the computers. Back when "Star Trek" was a hit show on television, viewers were amused by the easy discussions Captain Kirk and his crew carried on with a computer that replied in a sexy female voice. In Stanley Kubrick's movie "2001: A Space Odyssey," the computer HAL also chatted with the crew matter-of-factly, though it showed definite signs of "emotion" when it tried to take over control of the mission.

So much for science fiction. Verbal communication with processors in natural language via voice recognition and synthesis may become fact in the next decades. Image recognition will also become far more sophisticated than it is today. Actually the term should be image understanding, because the computer will not only identify pictures, including television images, but act on them. This capability has tremendous implications for the factory, the office, and the home, as well as for intelligence agencies.

Attaining these capabilities will require a great increase in machine intelligence—in the computer's ability to infer and deduce. That intelligence is the basis for speech recognition, image understanding, and automatic programming, and VLSI will ensure the requisite quantity of input/output.

In the systems of tomorrow, the electronic content—processors, memories, and peripheral chips—for the most part will be invisible to the user and taken for granted. Their functions will be paramount, and only the various I/O devices generally will be apparent. To use a favorite analogy of Robert Noyce, chairman of Intel Corp. in Santa Clara, Calif., the electronics will be like the electric motors in today's homes—largely unnoticed.

One of today's fascinating topics concerns the future of the personal computer and its close relative, the home computer. Looking ahead, Michael L. Dertouzos, director of the Laboratory for Computer Science at the Massachusetts Institute of Technology in Cambridge, Mass., defines a personal, or single-user, computer as a machine 64 bits wide containing from 1 to 12 megabytes of storage divided between mainframe and peripheral memory. This unit will almost always be capable of linking with other similar machines to form networks, he says, and will be used in the home, office, or elsewhere depending on its programming.

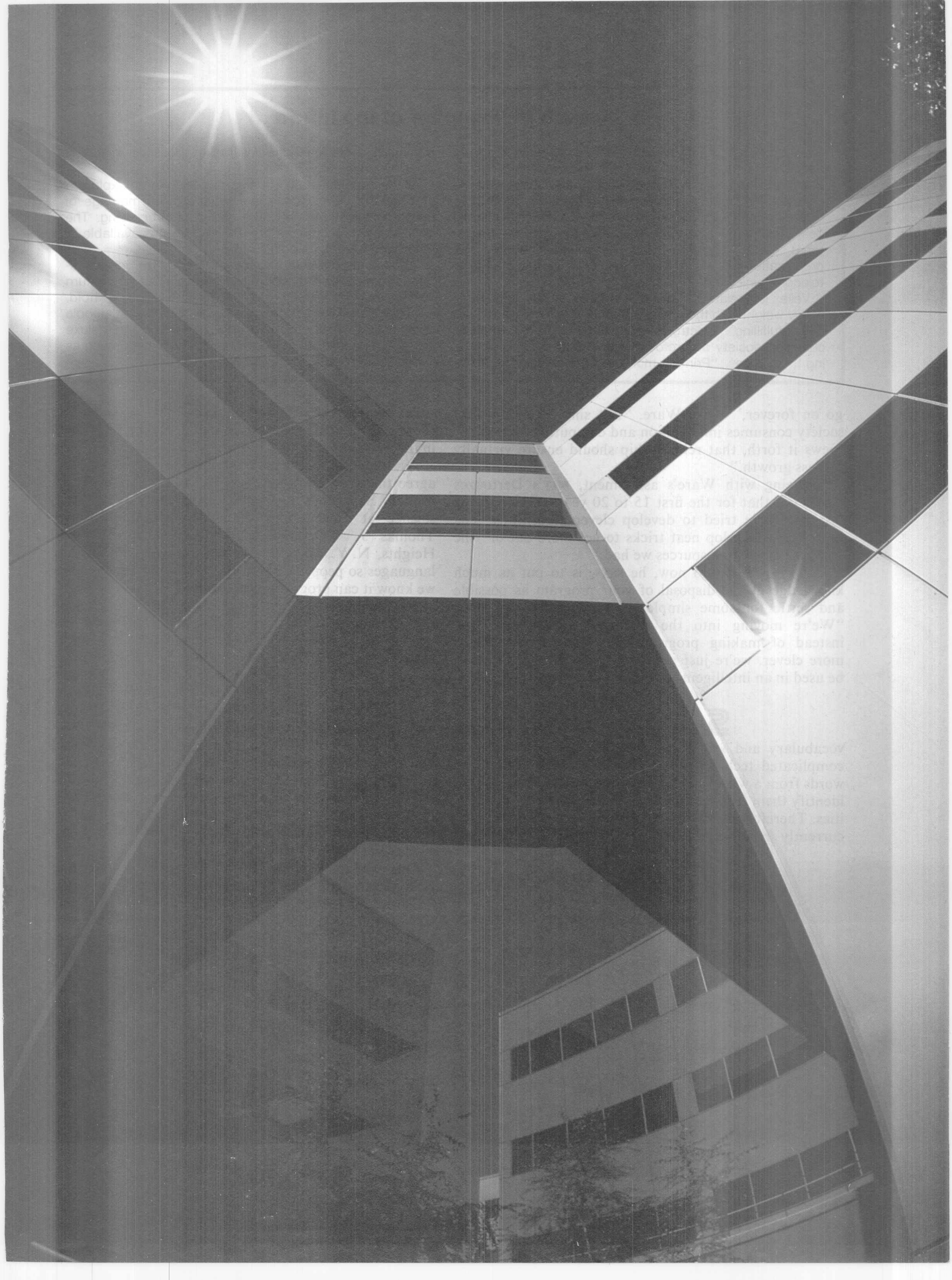
The availability of such communications linkups will be as important as the availability of hardware and programs. Willis H. Ware, a researcher at the Rand Corp. in Santa Monica, Calif., sees telecommunications support as a major spur to the small-computer market. He predicts the emergence of entrepreneurs who will interface a network of personal computers to offer new services such as electronic messages for subscribers.

Regarding trends in hardware and software, Ware notes that parallel computing—breaking up the workload of the central processor so it can handle data concurrently—is already being tried, and he expects this approach eventually to dominate computer architecture.

Software—instructions and programming of the data processors—will of necessity go back into hardware, where it started, Ware says. The reasons he cites are economic.

As the Rand researcher explains it, hardware was so expensive at the start of the computer era that software's chief role was to keep it running as much as possible. But to minimize system downtime, the software had to become more and more complex to the point where the expense of writing and implementing it soon rivaled hardware costs, which were steadily being pared by large-scale integration. The two cost curves have long since crossed, Ware observes, adding that burying—or re-interring—software in the hardware will also promote security.

What of overall growth prospects for the industry? "Computer people seem year after year to say, 'It can't



French philosopher of the future

Among practicing futurologists, Robert Veilex of France's Centre National d'Etudes des Télécommunications has an easier job than most who try to predict the future. Veilex is charged with formulating long-range plans for CNET, the research and development arm of the Direction Générale des Télécommunications (DGT), an agency of the Secrétariat d'Etat des Postes et Télécommunications, the organization that is in charge of running the country's telecommunications system.

Veilex is a relatively secure seer because his views carry heavy weight with the postal authority and thus are partially self-fulfilling. "Electronic technology is on the verge of changing society as profoundly as the invention of printing," he states. "Printing multiplied the diffusion of information in society; electronics makes possible a greater diffusion in real time."

All the conditions are at hand, he feels, for an explosion of what the French call "télématique," the marriage of telecommunications networks and data processing. The technology to accommodate this explosion is available to those who want it, he points out.

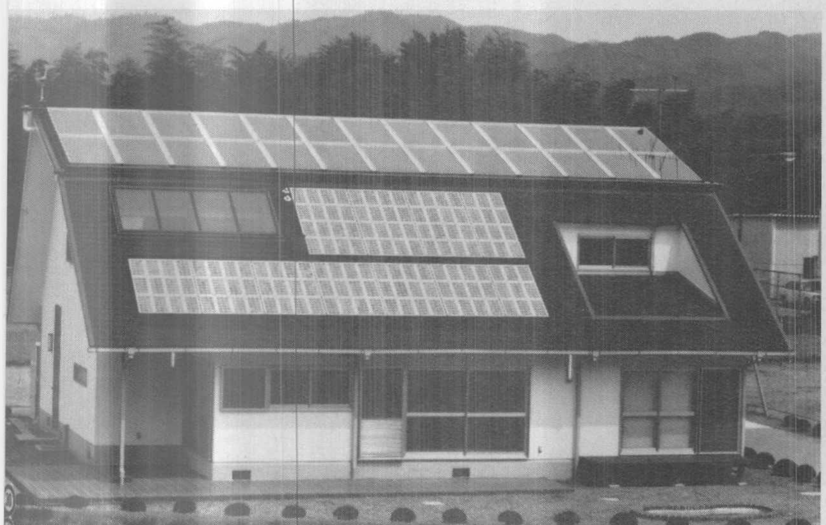
"It takes a couple of decades for people to get accustomed to a major invention," he goes on, "but by the turn of the century 'télématique' will have taken hold. Consumption of paper will fall drastically as people communicate electronically. Books will become deluxe items that people buy to show they're cultivated, much as leather-bound editions are today."

go on forever,' " says Ware. "But since every level of society consumes information and computing technology spews it forth, that relationship should ensure virtually endless growth."

Agreeing with Ware's assessment, MIT's Dertouzos points out that for the first 15 to 20 years of computing history people tried to develop clever algorithms. The idea was to develop neat tricks to get more out of "the meager hardware resources we had."

But the way to go now, he says, is to put as much knowledge at the disposal of your program as possible and settle for some simple, perhaps redundant rules. "We're moving into the domain of cognition. And instead of making programs smaller and algorithms more clever, we're just pumping in knowledge that can be used in an intelligent terminal."

Speech recognition—with very limited vocabulary and syntax—is certainly on the way. But complicated techniques are needed to pick out spoken words from a whole range of sounds and, having done so, identify them from among a whole dictionary of possibilities. Therefore, conversational interface with computers currently requires an unacceptably large amount of memory and processing power. Nevertheless, the advent of very large-scale integration could swing the tradeoff in favor of such a route.



As for software, most computer makers and users agree that a more productive way to write programs is needed. Says Joel S. Birnbaum, director of computer science at International Business Machines Corp.'s Thomas J. Watson Research Center in Yorktown Heights, N. Y., "There will have to be very high-level languages so people without programming experience as we know it can program future units."

And as the software becomes easier to foist on "friendlier" computers, specialists other than designers will take on a growing role in electronic technology. The mathematician's contribution will certainly gain in importance.

According to Kees Teer, managing director in charge of electronic systems at the Philips Research Laboratories in Eindhoven, the Netherlands, information theorists will play a larger part in the design of data-transmission systems and communications circuits. It is these specialists who will devise ways of monitoring a receiving line to check for signal similarities and cancel echoes. "Companies that know how to merge the various disciplines—engineering, the social sciences, mathematics—and put them to use in systems development will be the most successful," he predicts.

One technology that has relatively little importance today but is going to play a major role in information teleprocessing is micro-optics, Teer says. Miniature semiconductor lasers, fine and highly transparent glass fibers, new ways to manipulate laser beams, and optical imaging methods will yield new techniques for transmitting and storing information. He believes it will be possible to develop more intelligent equipment "that will be operated by verbal commands, announce if there is anything wrong with it, diagnose itself, and tell you how it is to be used."

The driving forces in electronics now and for the foreseeable future—solid-state technology and comput-

House in the sun. This Japanese-style home of the future was built to demonstrate the use of solar energy. Operated by Sharp Corp. for a project sponsored by the Ministry of International Trade and Industry, the house uses photovoltaic panels for electricity.

THE FIRST TO ENTER THE 21st CENTURY.

In this 50th anniversary issue of "Electronics" you will read all about the wonderful and exciting things that happened in the electronics industry during the past fifty years, a half century in which electronics played a major role in changing our way of life so drastically that no preceding half century even faintly compares. But drastic as were the changes in the last fifty years, we may see changes even more dramatic in the single decade of the upcoming 80's. By 1990 the electronics industry could reach the sum of $400 billion and represent 10% of the GNP. Computers, with their uncanny pervasiveness, will invade practically every industrial and consumer activity. The awesome power of electronics and its amazing ability to keep growing as an industry, makes it necessary to step back and reflect on our obligations to society. In fact, that's what anniversaries are for.

"The force of ideas is the fuel that leads to innovation; it is this shortage we have to be really concerned about."

Gertrude Stein said, "The Americans are the oldest people in the world because they were the first to enter the 20th century." Electronics was, for Americans, one of the most important gateways into the 20th century. Fifty years ago in April 1930, a magazine calling itself "Electronics" published its first issue and the opening article was entitled "The Future Service of Electronics to Mankind." And this, mind you, appeared 18 years B.T. (Before Transistors) which illustrates what Gertrude Stein meant. The three services we would select to head the list, none of which the writers in 1930 foresaw, are the invention of radar (which saved England in WW II), the invention of the transistor, and the development of the computer (which grows more powerful as it gets smaller). These are just three of the milestones in the past fifty years.

"In the 21st century information transfer will become power and electronics will be the dominant resource."

Today at the start of the 80's, the biggest threat to our nation economically, socially and politically is "oilflation." It's a threat which engulfs the whole world, hitting at some nations even harder than at our own. In 1974 OPEC increased the price of crude oil by 400%. By the end of 1979 that price doubled, bringing the increase to 800%. Projections for the next five years forecast another doubling, which means that in a period of ten years the price of oil will rise 1600%! Couple this figure with the ever increasing consumption of oil in all sectors of our society, industry, military, family, and it takes a minimum of expertise to see what persistent oilflation will do to us.

It is the obligation of the electronics industry to be the catalyst that will enable the U.S. to free itself of dependence on oil imports from anywhere in the world except the North American continent. Electronics technology can develop improved instruments in every area where energy is a factor such as the search for new oil and gas fields and the efficient control and management of energy usage in home, office and factory.

The 20th century started out as an electro-mechanical world and we Americans, by inventing, discovering, borrowing and adapting became the world leader. Having only 6% of the population, we used 30% of the world's energy. Energy usage was the yardstick of a nation's progress. Energy was, and still is, power, but in the 21st century information transfer will become power and electronics will be the dominant resource for the generation and storage of information. As an industry, we must lead the world into a workable 21st century. We must realize that the abundance of resources that was perceived in 1880 have become finite, if not scarce, in 1980.

"The Americans are the oldest people in the world because they were the first to enter the 20th century."

In the fifty years gone by, electronics helped us solve problems from the most mundane to the extraterrestrial. The force of ideas is the fuel that leads to innovation; it is this shortage we have to be really concerned about. In the decades to come, we must identify the crucial needs of society and put our electronics ingenuity to work to bridge the tide that threatens us all. Will we be the first to enter the 21st century?

Sincerely,

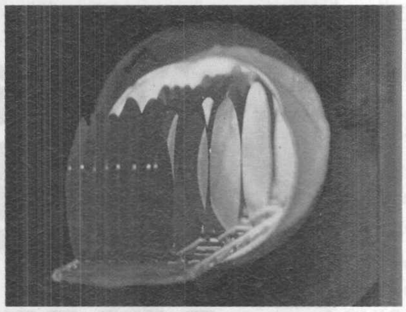
Seymour Schweber
President
Schweber Electronics

Bipolar is our business.

And our future.

MMI is committed to designing and delivering the bipolar product you want. In volume. On time.

Continued leadership in bipolar technology.



MMI has grown to become a $65 million company by consistently designing and delivering state-of-the-art bipolar LSI products. And now we're growing faster than ever.

Our tradition of excellence began with the industry's first 1K PROM in 1971. This was followed by the first 2K, 4K and 8K bipolar PROMs, by the first fast 8x8 multiplier, and then the 15 MHz FIFO. Our latest innovation is PAL™ programmable array logic, the LSI circuit which allows you to program your own logic on a chip.

And we'll continue the tradition, working hard in the future to develop products which are denser, faster and more economical . . . the products you want!

Delivery that keeps pace with our designs.

MMI has made a commitment to deliver large volumes of bipolar products. We currently ship—and will continue to ship—more bipolar PROMs than anyone else in the world.

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MMI was the first to install a 4-inch bipolar wafer fab line. And we will expand that line's capacity by another 80% before the end of 1980. At the same time, we have begun converting our 3-inch line to 4 inches and will double its output by mid-1981. We have also broken ground on a new assembly facility and expect it to be operational by September of this year. Over the next few years we'll spend 15-20% of every sales dollar on facilities and equipment to assure you volume delivery of MMI's bipolar LSI.

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Send for a specially prepared report which details MMI's engineering and production capability and outlines our extensive line of digital bipolar LSI products. Please address your requests to Applications Department, Monolithic Memories, Inc., 1165 E. Arques Ave., Sunnyvale, California 94086.

Monolithic Memories MMI

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"You're starting your own farm but you don't have much money. You'd better not plant asparagus. It takes two years to grow. Your money could run out before you've got a crop. That's why we started as an alternate source. Now we're ready for the asparagus business." W.J. Sanders III, President March, 1979

"It was a very good year for asparagus"

"Asparagus".

It was just a word, but it stuck. "Asparagus" symbolizes Advanced Micro Devices' innovative proprietary products.

The Rabbit™ the Am9512, is asparagus. It's the world's fastest TTL multiplier.

The Time Machine™ the Am9513, is. It's the most powerful timing device ever created. Our Am6012 12-bit DAC and our 256x4 RAM, the Am93422, made with the ion-implanted, oxide-isolated process (IMOX™) certainly are Asparagus.

We brought out some great new products in our growing line of MOS peripherals. We have a new generation of bipolar PROM's that utilize platinum-silicide fuses. Every one Asparagus.

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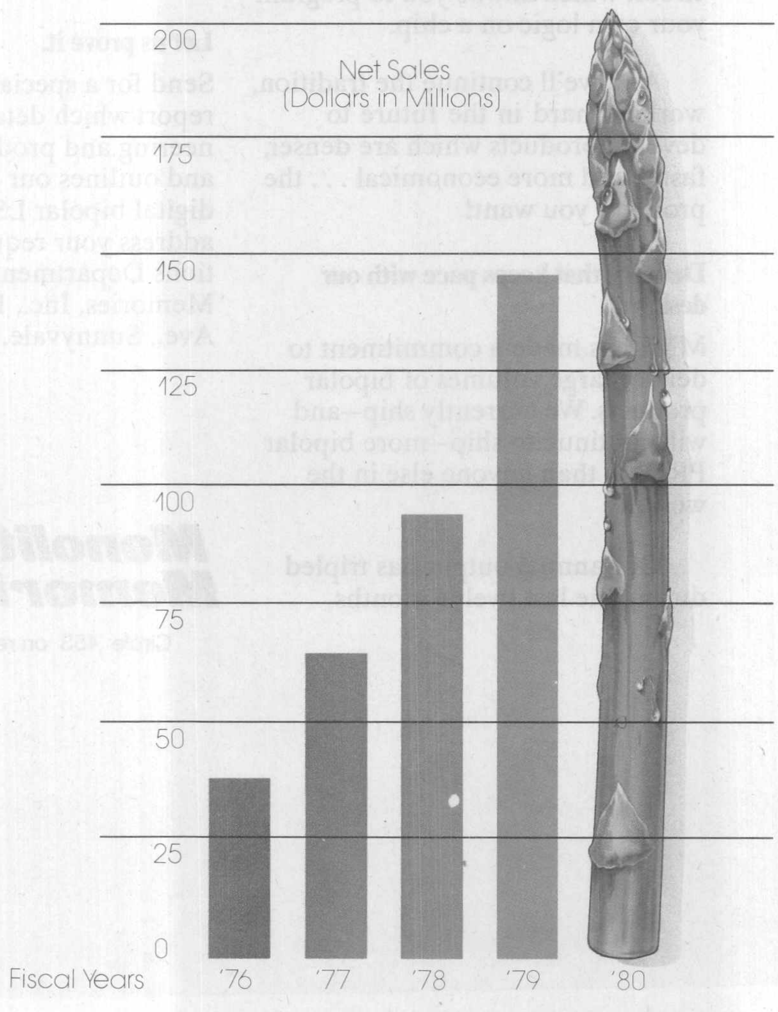
We've given a twenty-million dollar start to our new Technology Development Center, and our new Austin campus is off and running.

Advanced Micro Devices is eleven years old. When we started this business we decided to make building blocks of ever increasing complexity for the communications, computation and instrumentation markets. We made a commitment to excellence and quality. Every part built to MIL-STD-883 or better. Free.

We figured if we stuck to those two basic ideas, we'd pace the industry and become a major factor in integrated circuits world-wide.

And we were right.

Right, from the start.



Advanced Micro Devices

901 Thompson Place, Sunnyvale, CA 94086, Telephone (408) 732-2400

Circle 454 on Reader Service Card

	1980	1985	1990	1995	2000	2010	2020	After 2020	Never	Irrelevant question	Total
Most banks interconnected through a computer network	22	69	23	6	3	–	–	–	–	1	124
Electronic mail the main means of communication in business and industry	1	18	51	25	20	3	–	2	4	1	125
Direct access of individuals to data networks by ordinary telephone lines	16	40	38	18	7	2	–	1	1	2	125
TV-oriented interactive information systems for households	7	33	34	22	17	8	2	–	1	3	127
More than half of manufactured articles produced in plants with automated parts-making operations	1	15	39	29	19	9	2	4	1	–	119
More than half of manufactured articles produced in plants with automated assembly operations	–	1	18	23	37	10	4	13	10	–	116
"Paperless" administration: massive use of computers in offices and administrations	5	16	21	28	25	12	3	4	10	1	125
Automatic translation of unambiguous text	2	17	27	17	26	6	6	9	7	4	121
Computer-aided diagnosis in doctors' offices	9	32	39	24	11	3	–	2	3	1	124
Massive use in higher education of sophisticated computer aids	4	18	38	15	23	11	4	3	4	3	123
Intensive use of medical consultation at home by computer	1	3	11	17	24	15	6	15	18	6	116

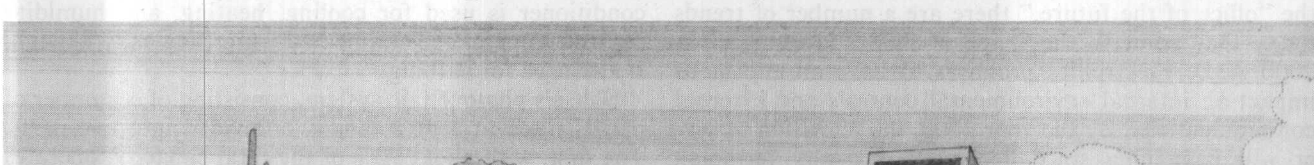
Note: Responses from 131 computer users and manufacturers

Source: Frederik R. Bull Foundation

er-communications proliferation—will gain momentum in large part because their economic tradeoffs will continue to be favorable. Higher densities and better performance will mark the semiconductor field for at least the next decade. Thus, integrated circuits' cost will continue to fall while their functions will continue to expand. But, some experts are already wondering how much further integration can be pushed before densities—computing power per chip—approach impractical levels. In other words, the problem arising at some point in the next decade may be how to exploit the astounding potential of VLSI.

That suggestion seems difficult to accept today when systems designers hunger for more and more intelligence and memory capacity. Indeed, the other side of the coin is a vision in which the total data-handling needs of the world would just begin to be met by the year 2000.

In this view, the level of information teleprocessing today is just a beginning. A planner such as Patricia M. Whiting-O'Keefe, director of SRI International's Infor-



Shining house of dreams. Ahwatukee, a Crow Indian word, is the name of a demonstration home run by five interconnected microcomputers. The computer system has five functions: information, electrical-load switching, environmental control, energy management, and security.

mation Sciences Laboratory in Palo Alto, says information management today is "done in bits and pieces, not in a big way. The timeliness of the information is the important thing. The faster you get it, the more successful you'll be."

Another concern only now being appreciated is computer security, or loss control. "These problems are proportional to the amount of data you're storing," explains Tom S. Eason, SRI's assistant director. "As the world moves toward distributed processing, particularly distributed data bases, loss-control problems increase out of proportion to the amount of data stored."

Consequently, Eason thinks it will become universal practice to incorporate loss-control specifications in the design of new computer systems and software.

Companies are becoming aware of security needs in computer-applications programs and planning ahead, he says. Meanwhile, there may be Government regulations requiring such controls and making companies using computers liable for losses. And pressure for loss-control requirements will mount as more and more money or documents convertible to money are represented in electronic form, Eason notes.

But the complexities of information handling have been faced for a long time—actually from the start of the Industrial Revolution. And the union of computers and communications will be reality by the end of this century because society wants it. Given that impetus, technology will solve the attendant problems.

Electronics is now entering the home in the form of various labor-saving and entertainment and educational accessories. Over the next decades, consumers will be offered a mixed bag of home-based products, ranging from personal computers to interactive "entertainment centers." And electronics will be the silent, unseen workhorse in appliances and security systems as well.

Although there has been nowhere near the planning for the "home of the future" that has been lavished on the "office of the future," there are a number of trends today that point to the shape of domestic living circa 2000 A.D. Electronics promises to have an enormous impact on internal environmental controls and external communications. By the year 2000, the television receiver will have long since become a two-way terminal, communicating with various data bases as well as receiving the information and entertainment that has been selected by the consumer.

Actually, two forms of video technology may be involved in communications. Bulk transmissions of information will be largely displayed on the television set, with person-to-person telecommunications being carried via telephone networks linking picture-phones.

Home electronics will be shaped, of course, by the structures that will be housing it—and their design may well reflect a continuing energy pinch.

An impressive example of the direction the use of solar energy for the home is taking can be found in the house constructed by Sharp Corp. at its Central Research Laboratory in Tenri, Japan, as part of a project that was sponsored by the Ministry of International Trade and Industry.

Computer fun. The TV set will gradually become a data terminal that displays information as well as broadcasting entertainment. Here a family uses the APF M1000 home entertainment system, which already contains some of the elements of future home computers.

Energy for that building is captured both by solar cells that convert sunlight directly into electricity and by a solar heat collector that heats water. The house also features a new type of heat-driven air conditioner. It makes use of heat exchangers for both perceptible and latent heat in the air; still another exchanger transfers heat from the solar-heated water to the air. The air conditioner is used for cooling, heating, and humidity control; some of the sun-heated water, logically enough, is also used for bathing.

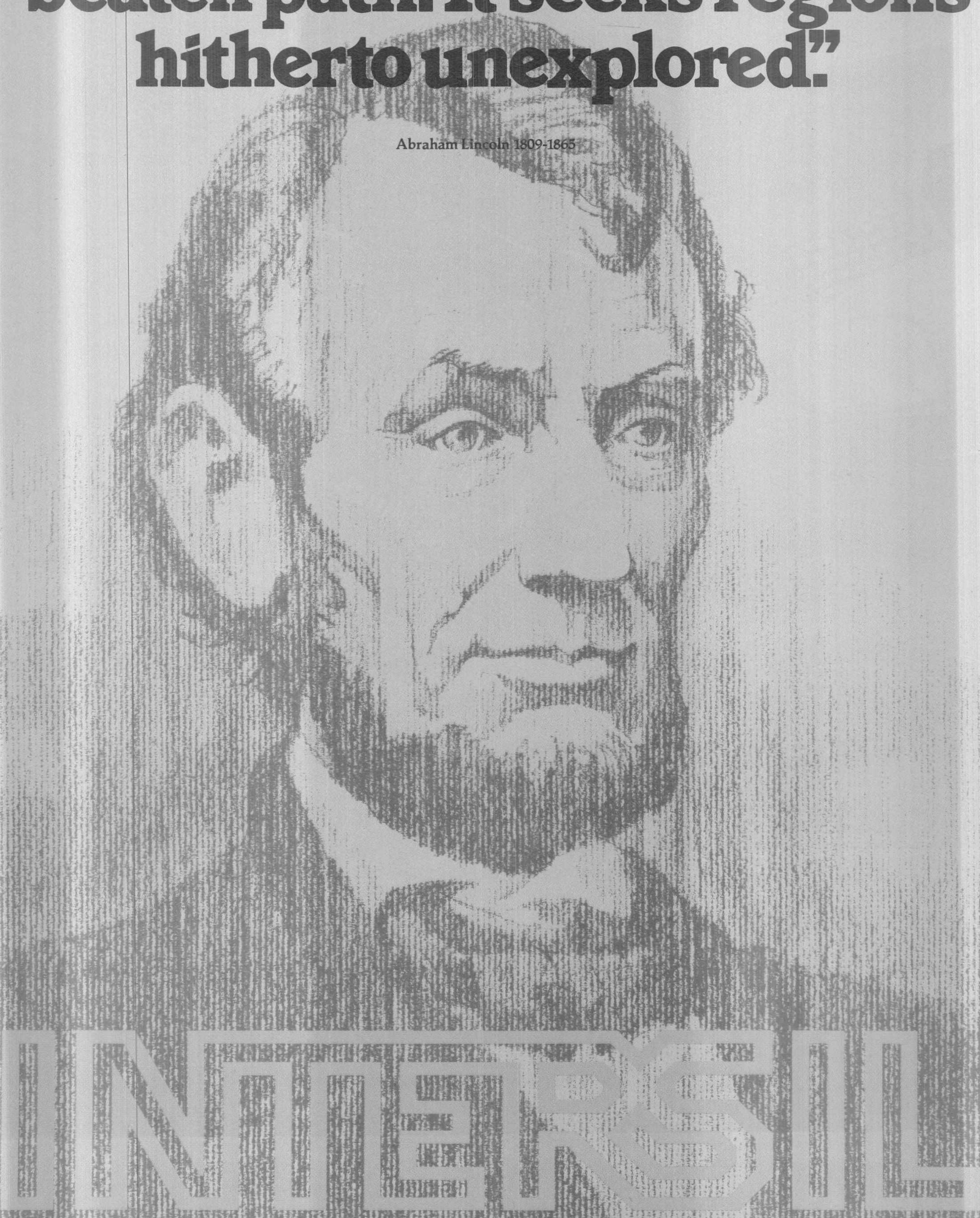
Sharp's photovoltaic system, consisting of a number of panels tilted at a 36.8° angle, is divided into two parts. The first, with about 90% of the total capacity, operates fans and pumps and is used as an auxiliary power supply for lighting. The second, with the remaining 10%, powers the master bedroom radio, the television set, and all the lighting throughout the house.

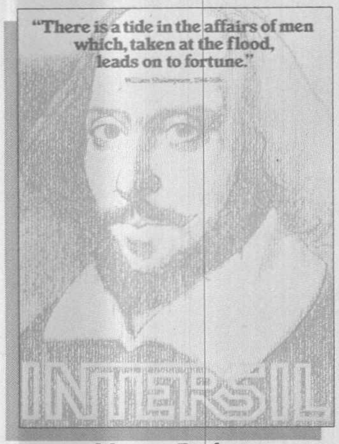
The first part has optimum outputs of 33.2 volts and 31.6 amperes. Its panels, covering 23 square meters and weighing 960 kilograms, charge a lead-acid battery with a nominal voltage of 24 V and capacity of 320 ampere-hours. The panels in the other part produce 16.6 V and 5.93 A optimally, total 2.1 m^2, and weigh 90 kg. They also charge a lead-acid battery, this one with a nominal voltage of 12 V and a capacity of 500 Ah.

An electronic information center in the house monitors the system, providing such data as outside temperatures, solar radiation levels, the power being generated,

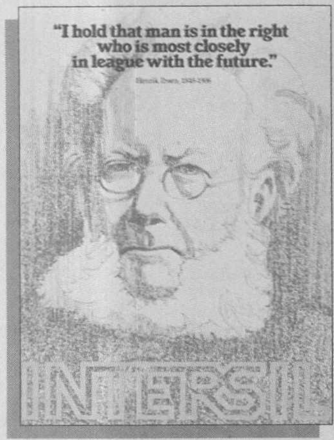
"Towering genius disdains a beaten path. It seeks regions hitherto unexplored."

Abraham Lincoln 1809-1865

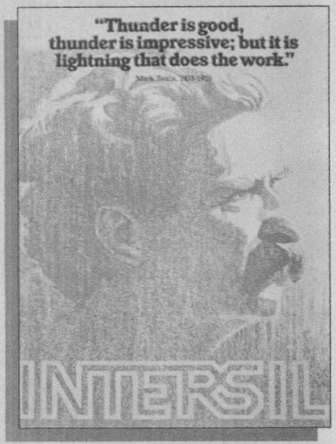




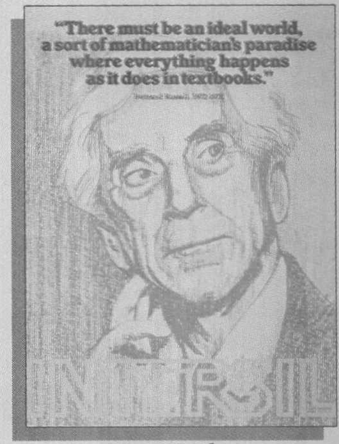
Memory Products



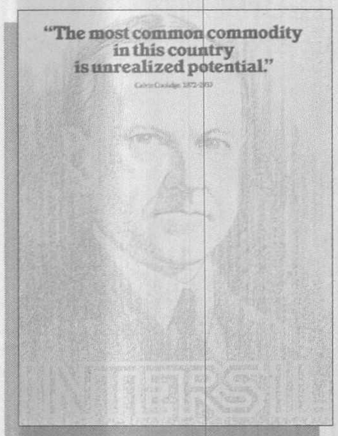
Data Acquisition Products



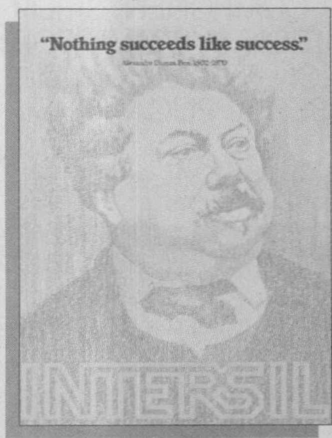
Low Power Products



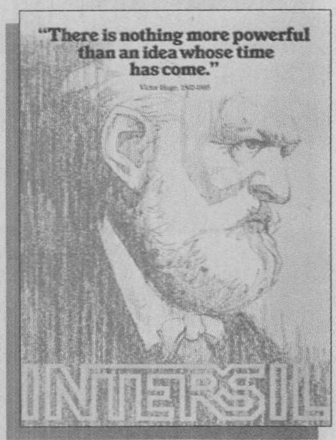
Linear Products



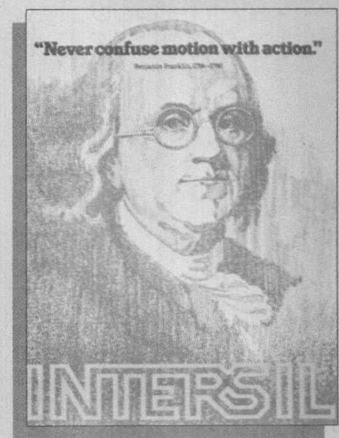
Microcomputers



Memory Systems



Analog Switches



VMOS Products

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In 1979, Intersil introduced twenty-nine integrated circuits over 7 product lines. Twenty-nine technological firsts. CMOS op amps. Commutating auto-zero amplifiers. An inexpensive CMOS 12-bit A/D converter. 21 deliverable types of VMOS power FETs. A CMOS version of the industry-standard 555 timer. CMOS EPROMs and microprocessors. And, high speed, low power upgrades of the industry standard 2147 Static RAMs.

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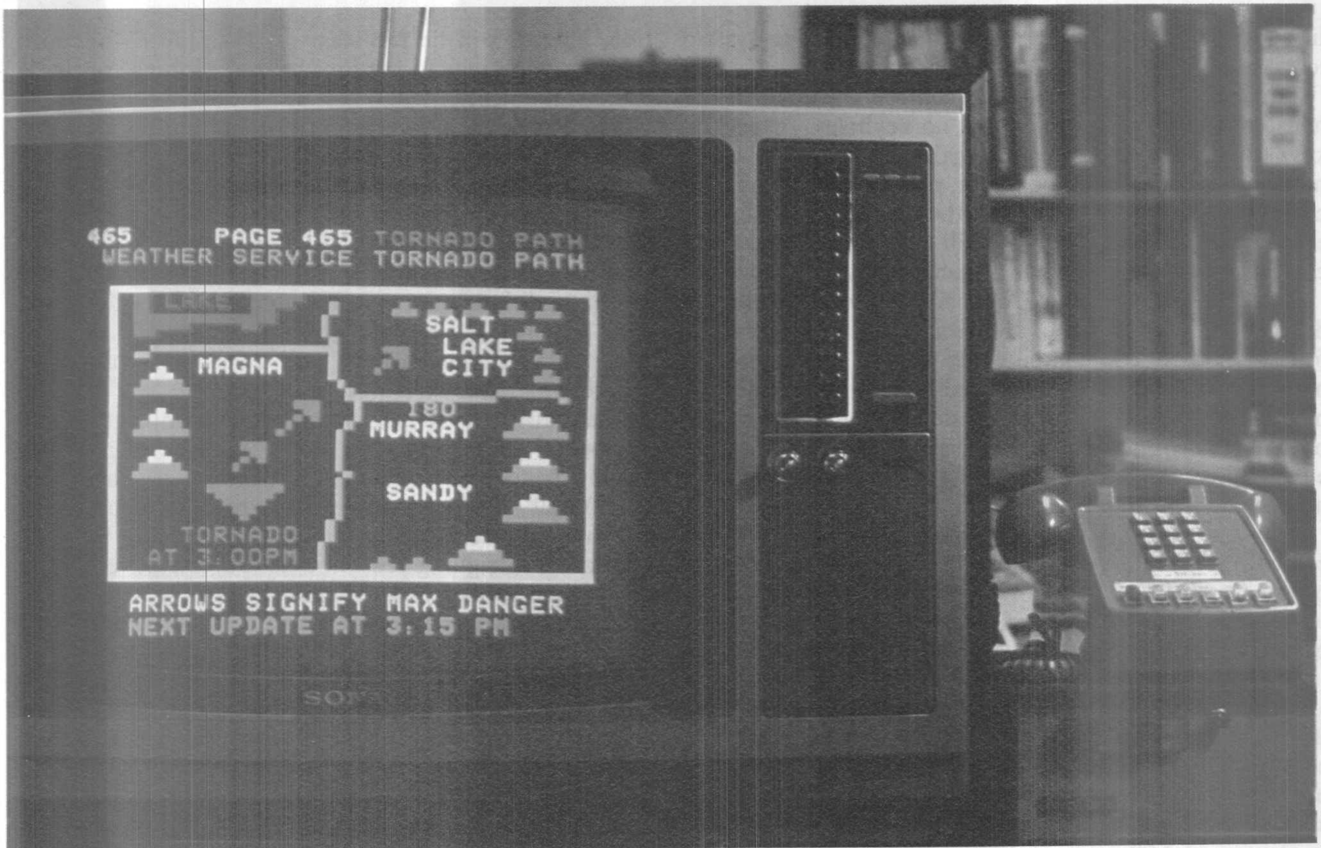


Information center. An important service in the future will be the availability of data-base information for the home transmitted to the TV set as needed. Viewdata (above) and teletext services are being tried out in the U. S. and are gaining rapid acceptance in Europe.

and collector-tank temperatures. It also shows room temperature and the water level and temperature of the Japanese-style bath. But beyond the functions of a sophisticated thermostat, it displays mail deliveries, heralds the arrival of visitors, and warns of intruders and such emergencies as fire.

Ahwatukee is a Crow Indian word that means "shining house of dreams." It is also the name of a partially completed 2,000-acre housing development south of Phoenix and of a specific house in that development. Touted as a home of the future, Ahwatukee features a computer system designed around its 6800 microprocessor by Motorola Inc.'s Semiconductor Group.

The system consists of five interconnected microcomputers, called nodes, located in different parts of the house. They divide the overall workload, redundancy being emphasized to minimize the effects of hardware failure. There is even a separate internode communications processor. Input/output is via a keyboard and TV set, while a floppy disk provides data storage.

The computer system at Ahwatukee has five functions: information, electrical-load switching, environmental control, energy management, and security. The information file is of two types—one that holds records such as bank statements, the other acting as a calendar for the storage of important dates.

Electrical-load switching allows the system to control lights, wall outlets, and other electrical equipment in the house, although the homeowner decides what conditions will cause the different loads to turn on and off. For example, lights are flicked on by a wall switch, but if the owner desires, the computer will lighten the gloom automatically according to the time of day or whether motion detectors indicate someone is in the room. Appliances plugged into wall sockets can also be activated or turned off in this way.

Environmental control is a bit more complicated than it is in a conventional house, because Ahwatukee is divided into three zones—the atrium, the alcove rooms, and the garage—each with its own temperature control. The computer system not only decides when to heat or cool each of these zones but by what means. It is programmed to choose the cheapest method possible. Thus, if the atrium is too warm on a summer evening, the computer weighs opening the windows (after first checking the outside temperature) against turning on the evaporative cooler favored in desert environments or, as a last resort, turning on the air conditioner.

Energy management at Ahwatukee is primarily an information process. The system keeps track of overall energy consumption as it monitors the individual consumption of particular loads. The homeowner can check any of these levels and even get off-site reports on them via telephone lines to a printer.

The security system responds to inputs from smoke and motion detectors located in almost every room to alert the homeowner to fire or intruders. It can also act

in conjunction with the electrical-load switching system to turn lights on and off when no one is at home.

Further, the security program controls the doors of the house at Ahwatukee, which has no keyholes. Instead, a keypad similar to the one on a calculator is used by the homeowner to get into the house; punching in the proper code gets the computer to open the door. The homeowner can change that code at will and even set certain combinations to work only on specified days of the week.

If security detects an alarm condition, its response will depend on the severity of the situation. For instance, a fire will cause the computer to sound alarms in the home, and it can be programmed to send a prerecorded phone message to the local fire departments. But if the problem is minor—perhaps just an improper code entered at the door—it prints a message on the homeowner's printer.

The key to making this project successful—and the critical factor in any home of the future—is the ease of programming these systems. Homeowners will not have to become computer programmers to enjoy their push-button habitat. The system will be transparent to them.

In fact, they will need to know only how to use the keyboard and follow the multiple-choice instructions displayed on the TV screen. Their instructions are converted into reference tables and stored. To prevent unauthorized changes, a password is required before any critical input can be made. The software for the project is written in MPL, a high-level language developed by Motorola and similar to PL/1.

By far the most exciting prospect to most is the availability of computers for personal use. As suggested in the description of the experimental home of the future, most of the applications of at-home computers will be transparent to the user, who will not need to be aware that a computer is at work. Computation, indeed, will be the least of these units' functions, taking a back seat to the jobs of data storage, retrieval, and communications.

Therefore, it is perhaps more accurate to predict that the home computer will be more a terminal for the world of stored information than a processing machine. A new industry will emerge to service what MIT's Michael L. Dertouzos calls the "information marketplace." This he describes as "a business medium in which people will buy and sell information as a commodity. It will become more important as more buyers and sellers join it, and a great part of this business will consist of data bases containing unique information."

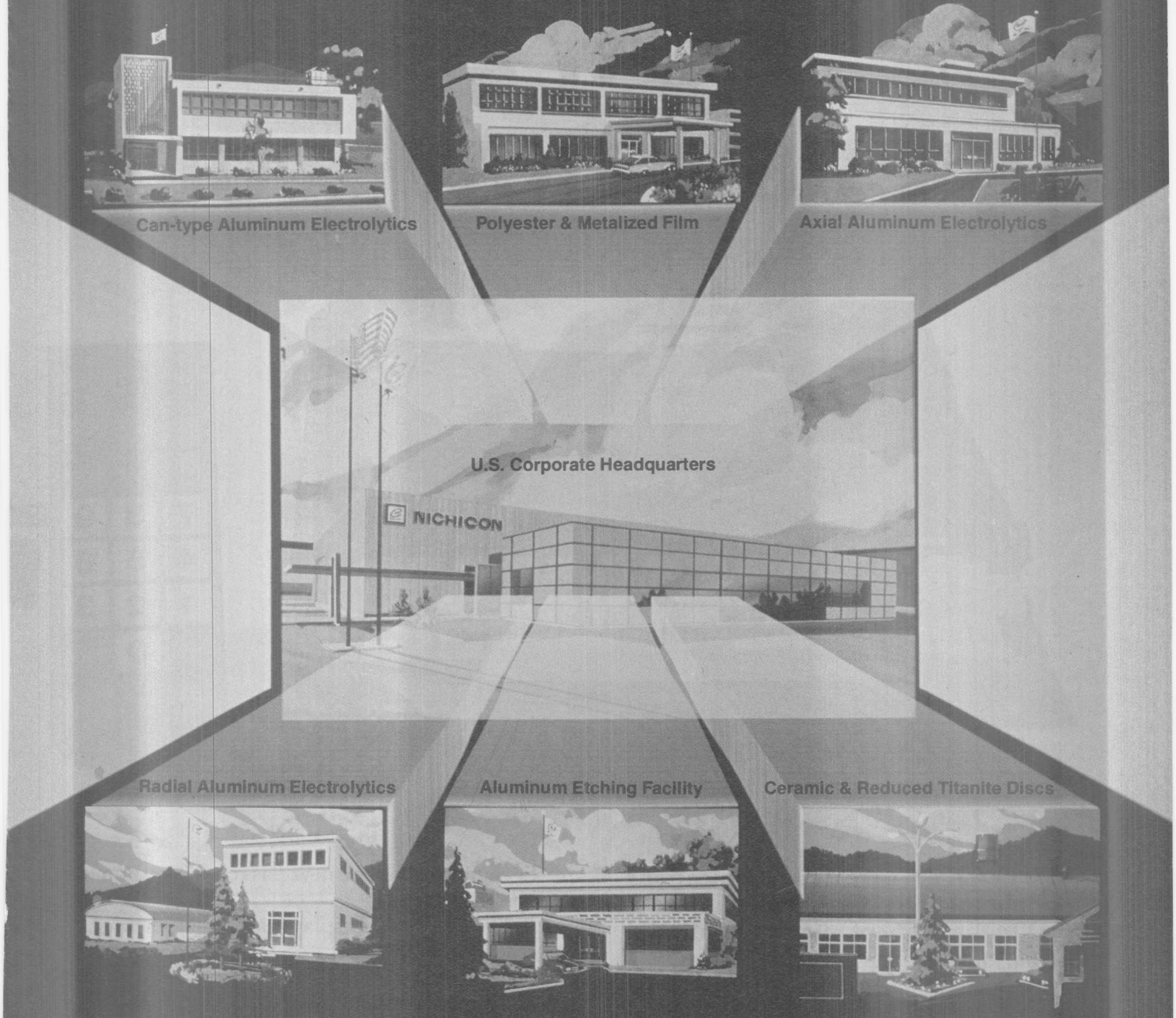
The data-base industry has other ramifications, in Dertouzos' view. For one, there will be a need for "yellow-pages entrepreneurs" who will charge a modest fee to tell information seekers what base to tap—a directory-of-directories service.

Another intriguing possibility is "reverse advertising," in which persons needing some product or service will enter requirements into a data base and the suppliers will find these customers by consulting that base. In short, it will be an electronically interactive marketplace.

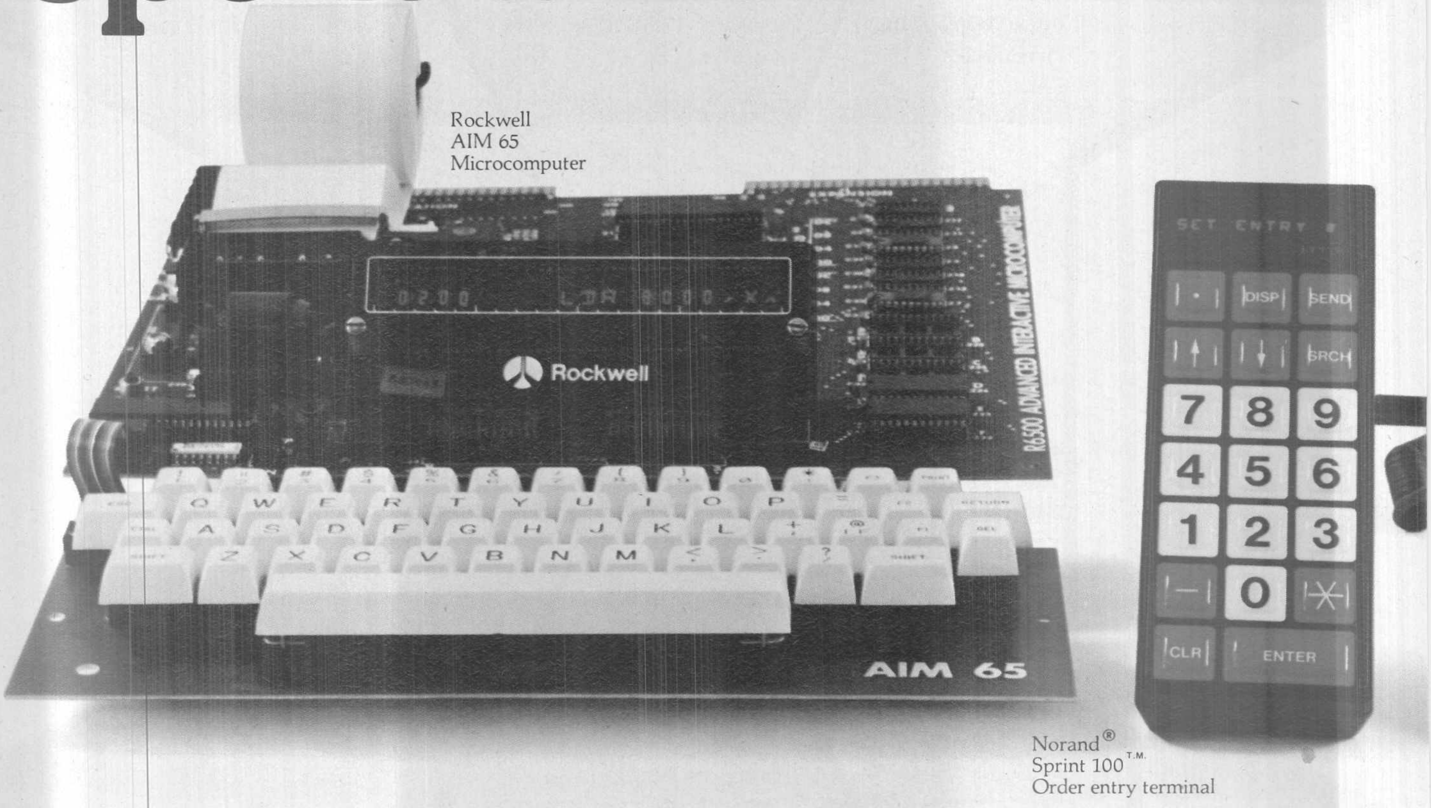
Another facet of this data marketplace is that it will provide employment for people involved in preparing and maintaining the information that the entrepreneur

Programmable fun. Equipped with a Texas Instruments microcomputer, "Big Trak" is one of a host of electronic toys that will influence children's ability to program computers. Designed by Milton Bradley, this toy answers to 16 individual commands.

Touchdown. Mattel's hand-held football game is another popular electronic toy that makes use of a microprocessor to control the action. Hand-held games will become more and more popular as new displays and processors of greater complexity are employed.


Can-type Aluminum Electrolytics
Polyester & Metalized Film
Axial Aluminum Electrolytics
U.S. Corporate Headquarters
NICHICON
Radial Aluminum Electrolytics
Aluminum Etching Facility
Ceramic & Reduced Titanite Discs

How Litronix' opens a new world



Rockwell AIM 65 Microcomputer

Norand® Sprint 100™ Order entry terminal

Now designers have a communications peripheral perfectly matched in size and cost to the world of microcomputers. Litronix invented the Intelligent Display* to give microcomputers a new way of "talking" to users in words, numbers or even sentences. And not surprisingly, these displays are already beginning to create a new class of microcomputer-based products.

Part Number	Features	Character Height	Horizontal Row Spacing	Vertical Row Spacing	Viewing Angle	Character Positions	Character Segments
DL-1416	Standard General Purpose Display	.160"	.250"	1.200"	±25°	4	16
DL-1414	Compact Display For Hand Held Equipment	.112"	.175"	.800"	±50°	4	16
DL-2416	Premium Display New Rugged Package	.160"	.250"	.800"	±50°	4	17

*Intelligent Display is a trademark of Litronix, Inc.

The Intelligent Display is an alphanumeric LED readout that incorporates ASCII decoder, multiplexer, memory and LED driver in a built-in CMOS IC. It interfaces simply and directly to any microprocessor bus, much like a RAM. Power is from a single +5V supply, and operating current is low enough for any battery powered device.

Litronix puts intelligent communications in the palm of your hand or anywhere panel space is limited. Three versions of the Intelligent Display are already available to fit a wide variety of applications. The smallest lets you fit 20 characters side by side in a space of only 3.5 inches.

Litronix' Intelligent Displays are already being used in the portable terminal, the low cost microcomputer and electronic translator above. They're also ideally suited for applications like control panel readouts. Handheld computer

Electronic wash. The pervasiveness of microprocessors is already apparent in this Whirlpool Corp. electronically controlled washer and dryer combination. Eventually microprocesssors will become just as widespread as electric motors are today.

sells. These are jobs that do not exist now.

Dertouzos warns, however, that the information marketplace will also require safeguards in the form of forward-looking regulations backed by comprehensive information laws. These would cover such things as privacy, authentications, protection of the individual, and penalties for abuse.

Perhaps the biggest payoff to society from the eventual development of the information marketplace will be the individualization of products and services, without loss of the cost benefits of mass production. The work of artisans that at one time personalized products has long since disappeared or become too costly for most people to afford.

"But the computer is the first technological artifact capable of individualizing products and services," Dertouzos observes. "Examples go all the way from shoes and clothes to personalized made-to-fit furniture to tailored services and information."

The intelligent terminal in the home, though a relatively simple machine, will be linked by cable, telephone, satellite, or other means to a vast network of computers churning away elsewhere. In effect, a person could order a personal clipping service of facts, delivered in real time, relating to a specific subject. Tapping the data bases, he or she could have a personalized newspaper delivered as well.

As cost barriers tumble, home terminals should proliferate at an astonishing rate. According to Martin L. Ernst, vice president of Arthur D. Little Inc., Cambridge, Mass., there are marketplace parallels to be found in the past. He points to the boom in automobiles in the 1920s, radios in the 1930s and 1940s, and television sets in the 1950s.

The future scenario for information teleprocessing in the home will be written around four technical and economic developments: the introduction of personal computers to the home; the availability of more intelligent, easier-to-use programs; the spread of "hidden" computers; and the development of distributed processing systems.

Most people would readily admit they would not know what to do with a home computer if they had one. And it is probably true they would not know what to do with any of today's computers. But for those who have projected the role of the computer into the future, the applications are many. Hardware, software, and costs will change, they say, as will the systems' applications.

The personal computer clearly will be used first for recreation and hobbies. The games will be both extensions of traditional favorites—chess and the like—and new ones made possible by electronics.

Hobbies, too, will enter the computer realm. Writes Joel Moses, professor of computer science and engineering at MIT, in a recent book he edited with Dertouzos, "The Computer Age: A Twenty-Year View."

"One effect of the mass media in the past century has been to homogenize experience by providing everyone with the same TV shows or newspaper columns. The mass media also tend to reduce most individuals to insignificance by building up a few personalities to superhuman proportions. Computer-based hobbies can work to reverse this trend by allowing different individuals to specialize in different areas and build up their self-esteem by virtue of their proficiency."

One of television's most serious failures has been its comparatively small impact on education. Indeed, there are some who believe TV has actually set back learning. Computers in the home may do a better job because they are by nature interactive—that is, they require active participation.

The drill-and-practice method of computer teaching is already routine in schools where it has achieved a certain amount of success in imparting specific skills. Whether computers will ever be acceptable teachers of concepts remains to be seen. It will be interesting to see if home use of computers will speed their acceptance in the school, the way hand-held calculators stimulated the development of hand-held teaching aids, such as those produced by Texas Instruments Inc. of Dallas and National Semiconductor Corp. of Santa Clara, Calif. Or it may be the reverse, with computer use in the school having a carryover to the home, just as the educational experience has always prompted the purchase of books outside school.

All those who have projected acceptance followed by explosive growth for the home computer emphasize that this proliferation must be accompanied by a communications hook-up. It appears that the telephone network will be adequate for data communications up to a point. For the transmission of long texts or pictures, however, a broadband conduit will offer a better link than the telephone lines. Chances are that both telephone and broadband will be used, depending on the type of information to be transmitted and the costs.

As a result, the home computer will have a role in

An intelligent associate for everyone

How will the powerful computer-communications systems of the future benefit man generally? J. Thomas Markley, president of Raytheon Data Systems Co. of Norwood, Mass., believes they will provide us with what he calls "the intelligent associate."

This Markley defines as a device that will take information processing outside glass-enclosed computer centers and beyond narrow services now shared by only a small portion of society.

An associate in this sense of the word is someone who seeks out and reports information and recommends action. Markley's intelligent associate will be a terminal-like device that will hook into data bases at home or at work and solve virtually any information-handling function that needs to be done.

It will be characterized, he feels, by eight principal attributes:

□ It will be a display-based terminal that any user can link to a data network. That means—in the U. S.—an English-language-based system in which any terminal built by anyone would react to the same command protocols.

□ It will have broad functional capabilities such as data entry, inquiry response, program development, and electronic mail. It will therefore have to store a lot of data.

□ It will be of a single, compatible family that can be upgraded from one to dozens of stations. This means communications compatibility as well as distributed processing.

□ It will be supported by easily upgradable sets of peripheral devices, implying standardized interfaces. The latest printer or CRT will be capable of being plugged in without inconveniencing the user.

□ It will be capable of many network operating modes, including the selection of transmission paths and data rates. The user will be able to choose the communications path and decide price advantages on the basis of bandwidth or speed.

□ It will be rich in software—that is, it will possess all the operating systems and executive software needed for any application. This means the cost of programming will have to be cut by training many entry-level people to program and by increasing the productivity of software specialists.

□ It will be available under a variety of labels, which means commonality—several manufacturers producing interchangeable equipment.

□ It will become reality only when its potential users are ready for it.

When will that be? "The intelligent associate will arrive none too soon," replies Markley. "The complexity and rate of change of modern life demand that man amplify his ability to apply intelligence to his life circumstances in faster, more effective ways. The intelligent associate will provide this amplification."

Forces he sees shaping the need for this partner are:

□ The productivity push. The intelligent associate will do for the office what machine tools and manufacturing processes did for the factory.

□ Increasing interdependence. To be effective, information must be shared and shared quickly.

□ The growth of technology. The challenge will be to help people understand how and where the new technologies fit into their lives.

□ The price-power curve. The economics of computer pricing favor the development of mass markets.

□ New directions in the computer industry. The profit potential of hardware for personal units is extremely high.

many forms of communication. Automated mail delivery, for example, becomes feasible when terminals in all households can be economically reached by central processors. Most mail is routine—bills, advertising, magazines, and some personal correspondence that could be delivered by computer. Even paying of bills can be done electronically, as some present bank setups already indicate.

Another benefit afforded by this interwoven system will be the ability to contact others in the net directly, sending either messages for particular persons or general information such as meeting notices.

As for electronic journalism, the resources for establishing the requisite data bases and devising the equipment are near at hand. Electronic news to the home is actually a logical continuation of recent trends in this field—computer typesetting and editing terminals.

Ordinarily the size of the tasks to be performed dictates the size and capacity of the computers to perform them. The situation is somewhat more complicated with the home computer. To MIT's Moses, the basic hardware bottleneck is likely to be the size of the main and backup memories.

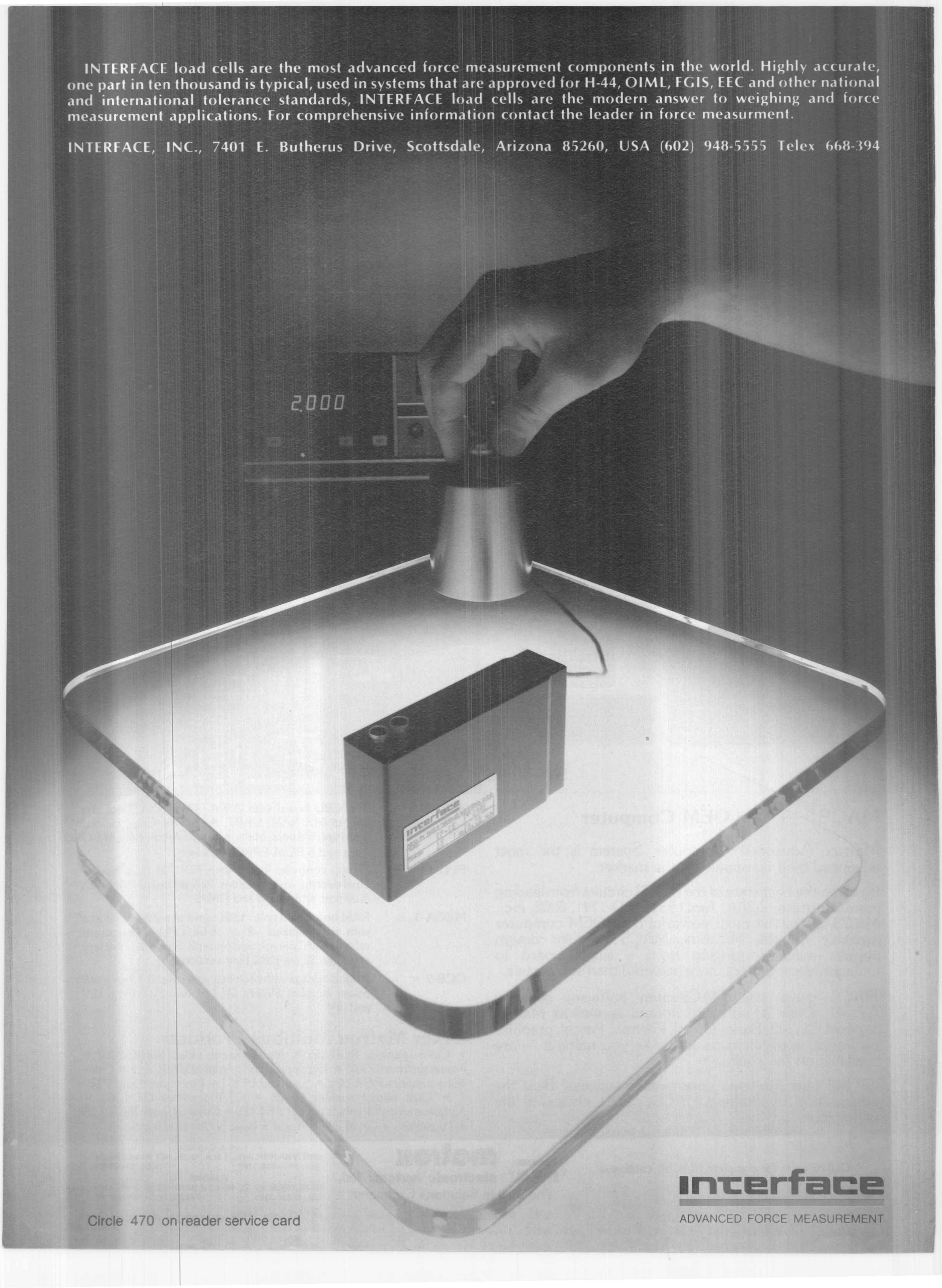
"A computer with a main memory of about 10 million bits will probably be satisfactory for most services," he writes. "A reasonable guess for the sale price of the home computer is about $500. The current value of a medium-speed computer with the desired memory size is about $500,000."

Is it reasonable to expect that the latter price will fall by a factor of 1,000 in fixed dollars during the next two decades? Extrapolating the trend in the last two decades would indicate an affirmative answer. Cost per computation has decreased about 30% every year during that time; if that rate is maintained for another 20 years, the 1,000-fold reduction could be achieved.

Then, too, others do not expect the home computer to require all that much memory because its functions will be kept simple, initially at least. Even electronic mail delivery, with all the complexities inherent in setting up the network, would not require a particularly powerful home terminal.

But a strong argument for the hefty machine envisioned by Moses for home use can be made by considering the software. If the computer is to be designed for ease of use, including natural language input and output, there has to be enough capacity to handle the software, the cost of which is already outstripping that of hardware in most installations. To reverse this trend for the home computer, it will probably be necessary to put greater capability into the hardware.

But man does not live by information processing alone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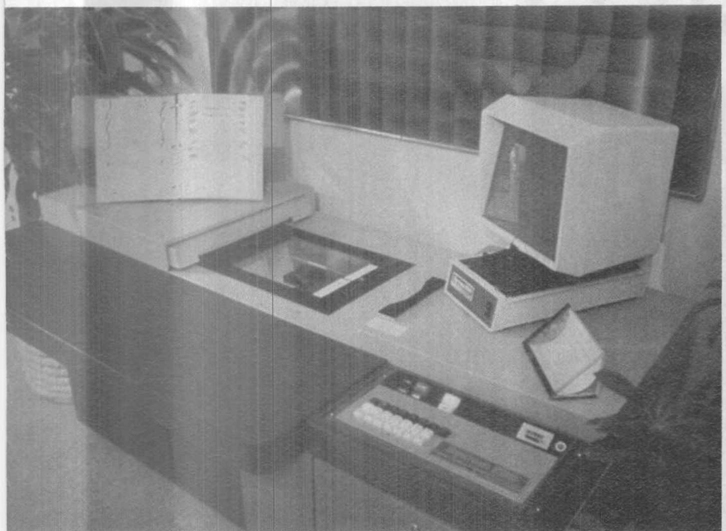

Office automation. The electronic office of the future has started to appear. Management consulting firm Micronet has set up the Paperless Office in which all information and correspondence is handled electronically. Each desk has a variety of displays.

Getting the word. Micronet's future office makes extensive use of dictation equipment. Information may be entered by telephone or from desktop and portable tape-cassette recorders. The system then assigns transcription according to typists' workloads or by priority.

—entertainment will always be a major application of home electronics, as it has been since the beginning of radio and television broadcasting. And the center of home entertainment for the vast majority of consumers right now is the television set. Remarkable changes are taking shape in the way people use their TV receivers.

In a sense, TV viewers are gaining control of their sets, thanks to innovations such as the video cassette recorder, the video disk, and the pay-program selector. Two-way cable television, once thought just around the video corner, will finally emerge in the next two decades. As a result, broadcast television, with its dependence on mass audience acceptance and programs aimed at the lowest common denominator, may be as old-fashioned as an "I Love Lucy" rerun.

That, in essence, is the thinking of Gerhardt Hanneman, head of the Media 90 project at the University of Southern California's Annenberg School of Communications, which is charged with forecasting changes in television during the remainder of this century.

As associate dean for research at the school and director of the project, Hanneman at this writing is in the first phase of the three-year project. He is working on the premise that the future of TV is being shaped by the development of many alternative uses of the screen and by the public's growing willingness to pay for new video services.

As a result, "the existing network structures are becoming anachronistic," he says. The trend is clear, in his view. About 20% of the nation is subscribing to cable TV, for one thing, and an ever-growing number of these subscribers are attracted to the pay-TV packages that community antenna TV operators offer.

Further, he points out that video cassette recorders are growing in sales and video disks are not far off. "Everyone believes, and so do we, that VCR's impact will be profound." Finally, independent TV stations are going on satellite for nationwide distribution and the high ratings of public broadcasting programs are cutting into network dominance.

"People are going to be using their TV screens a lot more, but they're going to be using them less to watch network TV," Hanneman predicts. He estimates the networks' loss at 20% by 1990, particularly in the big cities. They will then reduce their prime-time offerings, he believes, forcing local broadcasters to buy programming from other sources until they are no longer affiliated with single major networks.

Much of what the Media 90 research is finding reflects a changing attitude toward the role of the TV set, particularly toward displaying information other than standard TV fare. Says Hanneman: "People have become more comfortable with what we call 'mediated communications,' using technology to interact with others. When we first started doing studies in 1973, people were very much against that.

"Now they'll tell you they desire pay entertainment services and interaction for civic functions or to use the TV set to renew a driver's license, say. They're also willing to shop remotely; in the early '70s they wanted to touch the merchandise before buying. And businessmen are particularly willing to use teleconferencing to substitute for routine business travel.

"The fact that people are interested not only in things like shopping but also in two-way picture interaction with their commercial associates, neighbors, friends, and relatives forecasts tremendously increased use of interface units between the TV set and the phone. And what that's going to do is to start devaluing face-to-face interaction. That will have profound implications for society."

Though yet to have a massive effect worldwide, the viewdata and teletext systems developed in Britain are considered models of information services for the home. Britons have had teletext broadcasts for several years,

allows a viewer to contact a computer data bank by phone and receive replies on his television set—is now a public service, though with only a few thousand subscribers so far.

Holding the service back now is price, but that is one problem that developments in microcircuitry will correct over the next two decades. Martin Wolfendon, a product marketing manager for GEC Semiconductors Ltd., predicts teletext decoders will be standard on most British TV sets within five years. Today's $60 price for a teletext module will drop to $12, he says, and a combined teletext and viewdata chip set will cost $120 from the chip maker.

There are other signs that these services will soon have their day. Some 120 information providers are staking out their claims in anticipation of a big market. And subscribers very soon will be able to order goods via Prestel, quoting only their credit card numbers. Also, the viewdata and teletext concepts are spreading from England to the rest of Europe and the U. S.

One add-on for the teletext system is being developed at the British Broadcasting Corporation's Kingwood Warren Research Centre. This new unit incorporates a light-pen bar-code reader attached to a microprocessor, and it can be used to program a week's viewing—switching on and selecting the right channel—when the viewer runs the light pen over a bar code printed alongside each listing in the television program guide.

Echoing the idea of personalized TV programming, Boris Townsend, head of the Independent Broadcasting Authority's Information Service at its Crawley Court research headquarters, points out that all broadcast material could carry coded classifications for sports, news drama, comedy, and so on and could be used to turn on a smart video recorder to

"Such a recorder could play back to you over breakfast the programming you'd previously chosen. Our studios could run all night churning out recorded, labeled programs mixed with news, while your domestic recorder compiles your own minority-taste program."

Broadcasts from satellites directly to homes will become practical in the next decade. And if all goes well, a pair of European TV satellites will soon be launched jointly by West Germany and France with enough power to reach through much of Western Europe. In preparation for the launching of the two, five television channels in the 12-gigahertz frequency band have been allocated to each European country.

Electronic controls for home appliances are already gaining ground, with the success of programmable microwave ranges an important contributor to acceptance of this approach by the rather conservative home appliance industry. And as microprocessors become cheaper, there is no reason to believe the demand will abate.

Ranges will be programmable to do a series of tasks based on time and temperature. Washing machines will cycle according to the condition of the clothing rather than time. And what homeowner has not dreamed of a programmable lawn mower he can "teach" to cut a specific yard by itself? The big plus here is that the functions of appliances are restricted to well-defined tasks that can be controlled by means of a low-cost microprocessor.

The energy crunch has spurred interest in electronic heating and cooling controls that may be in universal application by 2000, as the cost of the electronic components declines and that of energy increases. Though solar energy, both electrical and thermal, will play an increasingly important part in energy generation, this source

A reading on the 'electronic book'

Individual access to information takes many forms in the many views of today's prognosticators. To some, it is important that the personal information-processing unit of the future be portable.

For example, Lawrence Seligman, vice president of Data General Corp., Westwood, Mass., envisions a data terminal about the size of a paperback book—something that will fit into a pocket or hang from the belt. It would not have much in the way of mass memory, of course, but could link up with data bases by way of powerful communications satellites.

"As a substitute for the telephone and other instruments, the unit we're talking about would operate at very short wavelengths, very high radio frequencies—perhaps millimeter-wave frequencies," Seligman says.

But he foresees other functions for these booksized displays. As their data-storage density increases, video disks may serve as the inexpensive "razor blades" of information for the "razors"—that is, the display devices.

"I can see the technology improving to the point where in 20 years something the size of a book, perhaps, could be inserted in a small video disk and read from the display," says Seligman. Thus, the unit would not only be a portable telephone and computer but a means to read information stored on video disks.

Now assuming that the necessary video disk and replay technology are available, there is another problem to solve before this capability can be realized, and that is retrieval. Seligman expects the answer to lie in disks carrying abstracts of available works, lengthy excerpts, and finally whole articles. Subscribers would then skim the abstracts in much the way they would review technical material today in selecting subjects to read in full. They would not read complete disks but would rather retrieve the desired information with the help of the abstract disks.

Seligman conjures up one other chapter for the "electronic book." Having gained access to the video disk data, the user may even take notes while reading. "You might use the leftover bandwidth on the disk to insert the notes in spaces appropriate to the information you've been reading," he suggests. "You'd then have text and comments together, the equivalent of marginal notations."

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will still be primarily employed to augment existing resources.

Electronics will not be expected to generate as much energy as other resources, but it is being counted on to conserve what is used. William George, corporate vice president for product development at Honeywell Inc. in Minneapolis, sees microprocessor-based systems running future residential electrical, heating, and air-conditioning systems in much the way they control those functions in commercial buildings today. The pilot light on a furnace will have gone the way of the buggy whip by 1985, as a matter of public policy, says William McDonnell, vice president and general manager of the Residential Controls Center at Honeywell.

Various metering schemes to reduce residential energy consumption are in place in some cities, like Detroit, but McDonnell's hunch is that Americans will reject the European idea of a central station's automatically shutting off residential water heaters or other appliances to conserve energy. Instead, different rates will be offered for low- and high-demand periods to shave peak power demands and reduce fuel costs.

Eventually, the home appliance and environmental energy control systems, though run by dedicated microcomputers, will be linked in the home information center. Robert Stenstrom, manager of technology planning at Honeywell's Residential Controls Center, sees a future in which "microprocessors will be as common as fractional horsepower motors."

Comparing the spread of microprocessors to the number of motors in the home is a popular theme. It implies an ubiquitous but unseen presence to be felt in the coming years.

The computer-communications marriage will narrow the distance between workplace and home.

Joel S. Birnbaum, director of computer science at IBM Corp.'s Thomas J. Watson Research Center in Yorktown Heights, N. Y., points out that the trend is less a matter of the office moving into the home than of extended electronic offices that executives will be able to take about with them.

There appears to be little inclination, though, to transfer the office *in toto* into the home even if the technology to do so is available. There may be some interest in the next decades in cutting business travel to reduce energy consumption, in which case audio/video conferences will increase. Commuting to and from work may be cut to save fuel, too—again with on-screen, face-to-face interchanges allowing this to be done.

In the factory, productivity and the quality of products are lagging. "Automation" has always been the knee-jerk proposal to solve this problem, but most products (as opposed to processes) do not lend themselves well to automation as we know it today.

Technology's answer is flexible automation, which will be discussed at length later in this chapter. It can be cost-effective even when the number of parts to be made is small or the design or fit changes often. And that suggests intelligent robots, the kind that can sense and respond to a variety of conditions.

Speaking of computers. Both speech synthesis, demonstrated above at Bell Laboratories, and speech recognition will be important developments in the future use of computers. They will enable users who have no training to communicate with computers.

These robots will need intelligence and vision-mating to the computer, like charge-coupled-device cameras with microprocessor controls. They will be able to manipulate materials—metal, cloth, leather, plastic, and so on—efficiently even for small production runs.

If plant-productivity statistics can be worrisome, those for the white-collar side of business are downright distressing. Industrialists over the past 30 years invested a yearly average of $20,000 per blue-collar worker in the form of tools and support systems and realized a 95% improvement in individual output. In the office, business invested a sum equal to approximately $2,000 for each employee over the same period and squeezed out a mere 4% gain in productivity.

Other versions of these statistics yield the same message. It is estimated, for instance, that while the productivity of the American factory worker increased by 84% in the past decade, the office worker's output inched ahead only 0.4%. One of the reasons for this disparity, of course, is simply that American business spends less per office worker. According to Datapoint Corp., San Antonio, Texas, current capital expenditures to create a U.S. factory job average about $24,000, against just $3,000 per office job.

From another angle, Ing. C. Olivetti & C. of Ivrea, Italy, notes that office staffs in the Western industrialized countries are estimated to have grown by 45% though overall work forces have increased only 6%. According to one study, 51% of the American work force may be grouped in the white-collar category now, up from 42% in 1958.

Raising the productivity of office workers clearly will

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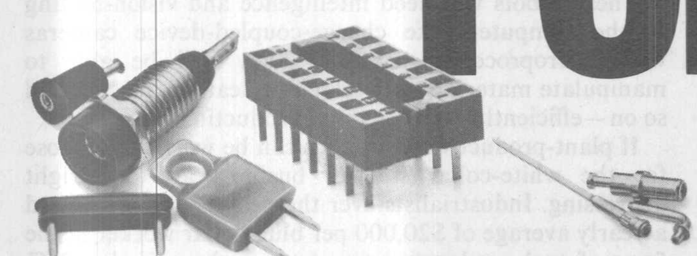

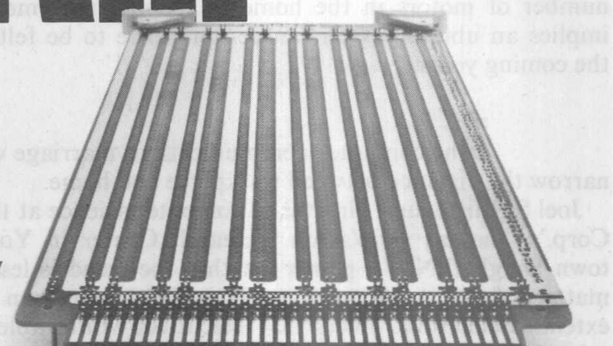

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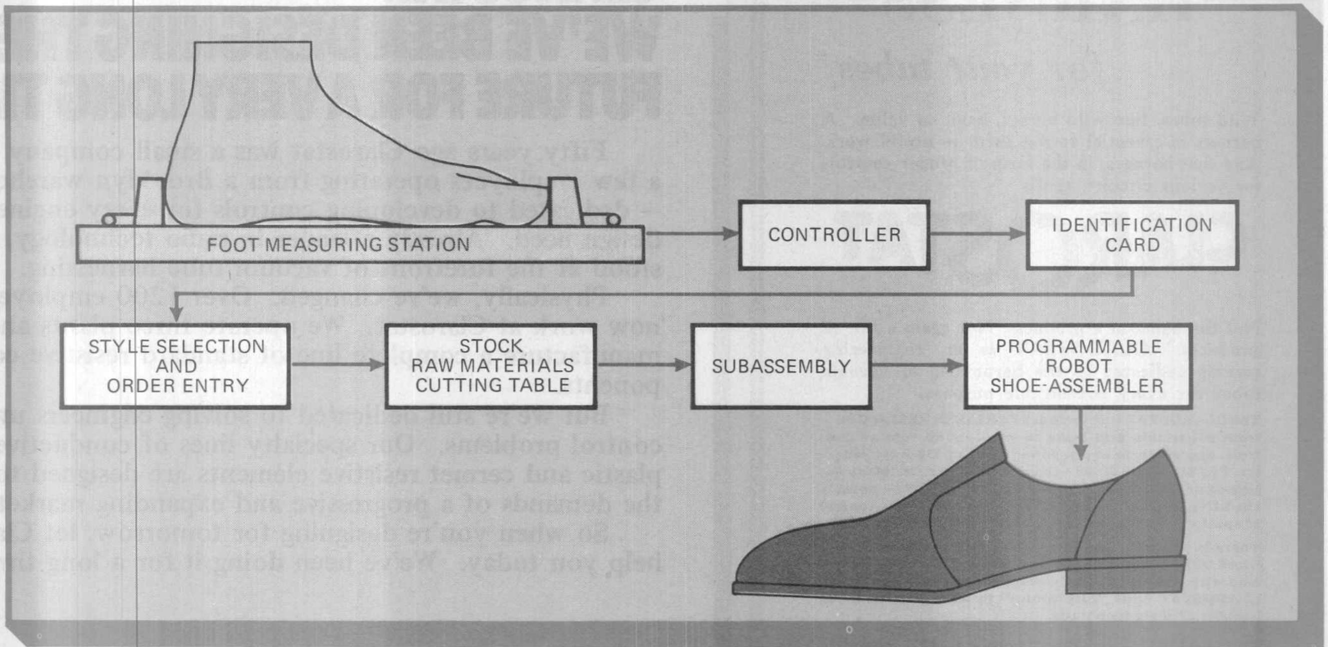


Shoe store. As envisioned by Michael Dertouzos in the book, "The Computer Age: A Twenty-Year View," an automated shoe factory will tailor its products to individuals. After a computerized "fitting," the customer will pick a style and robots will make the shoes on the spot.

involve electronics. Earle D. Jones, executive director of SRI's Advanced Development division in Menlo Park, Calif., describes the situation:

"People generally think that the productivity of the American worker is the key to everything, that more output per man-hour is necessary. Consequently, everyone thinks in terms of automation.

"The problem is that only one third of our total GNP is derived from manufacturing. The rest stems from service businesses. . . . Office automation will be the biggest contributor to increasing productivity of this service sector of the GNP."

Many of the technical objectives in gearing up the office of the future will be the same as those involved in establishing access to data bases in the home, except that the office is more concerned with documents and records, of course, and information teleprocessing will be even more important there.

The office-of-the-future concept has been bandied about so long that it has lost much of its power to dazzle. But the recent emergence of a trend to the subtle linking of word- and data-processing functions should succeed in restoring its appeal.

There are two ways of looking at how this trend will develop further. One is to focus on the technology itself and make assumptions about how it will be used. The other is to define the marketplace forces that will push the technology toward specific applications.

Edward P. Gistaro, senior vice president and general manager of the Data Processing division of Datapoint, chooses the latter approach:

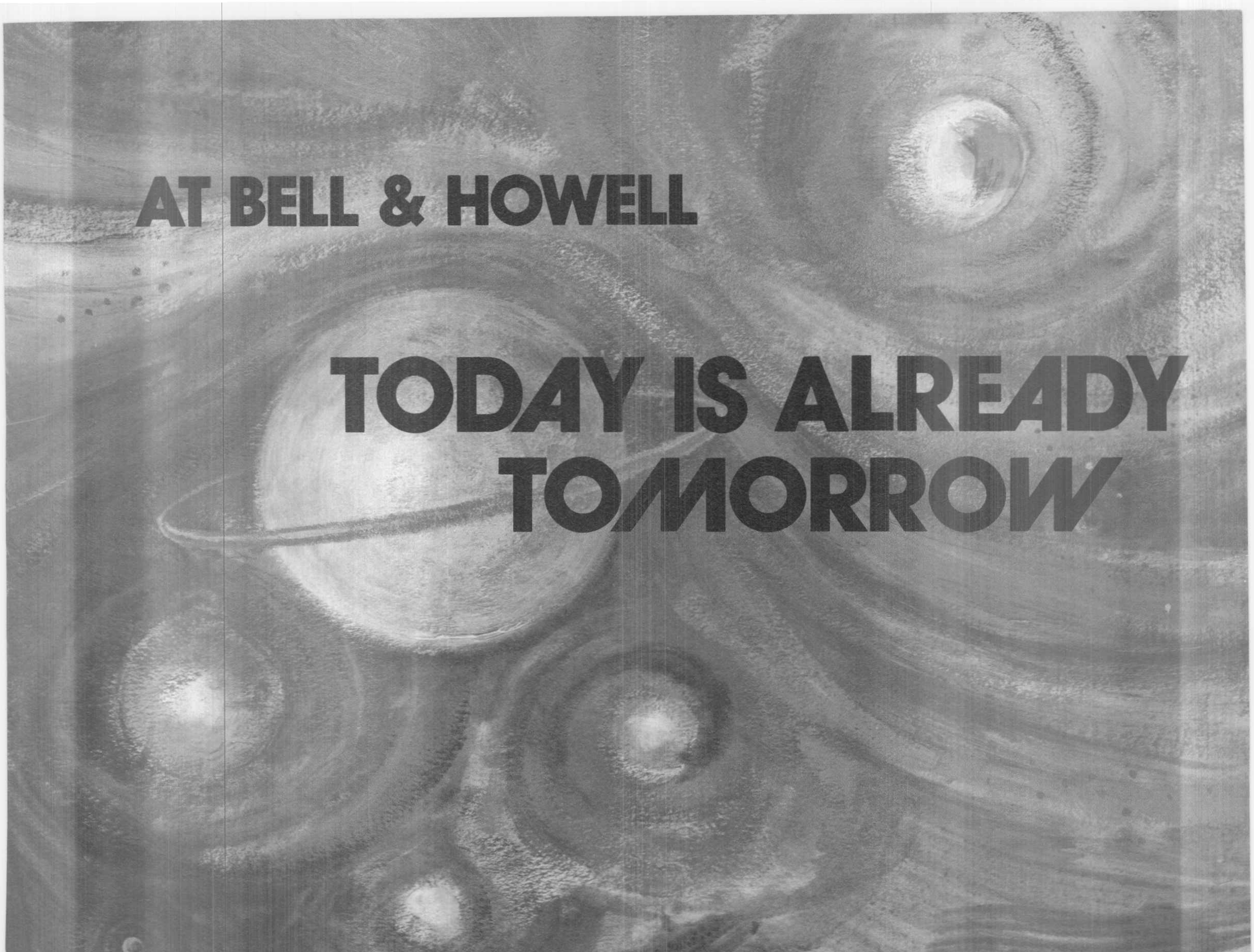
"The first major push for the integration of mundane functions—telephone, typewriter, mailbox, and copier—with a common information base would bring a tremendous amount of efficiency to the office," he says. "Ironically we automated all the very complex things in our society first—blast furnaces, industrial processes, telephone switching systems, spacecraft. Yet the office environment, which is so familiar to all of us, we've been content to improve on a piecemeal basis."

Future office automation systems will tend to be distributed processing centers operating from a common data base, Gistaro believes. He sees a close parallel between the emergence of distributed processing in electronic data-processing applications and the way offices will eventually be organized. Each unit of the system, even the mail room, will be able to program procedures to fit its own operation, but each will be tied to the central data base.

The automation of office record keeping will leave another problem to be solved in the next decade: what to do with the paper already on file. Some form of optical character-recognition equipment will be needed to get those records into electronic storage, though, as one observer suggests, close scanning may lead many companies to throw out 90% of them.

The goal then is to integrate data processing and word processing with electronic mail and voice or data communications to form what Datapoint calls the "electronic office." And some form of content-addressable memory system will be a must, according to Gerald L. Cullen, vice president for product marketing. This approach to accessing information may meet a long-time need in office automation—the ability to get at a letter or document filed electronically without a specific tag on it. In other words, the document can go into the data base without an identifying symbol and be retrieved by surveying any number of key words.

For example, say a manager sends out a letter to Mr. Ito Watanabe concerning production of yo-yos in Okura, Japan. That memo could be stored in the system under no particular category and then pulled out by a check of



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key words. Given "Ito Watanabe," the system would display a list of all correspondence and memos in which that name appeared. Or it could be possible to get a list of all communications dealing with yo-yos or with Okura. If the user recalls two key words the search is sharply narrowed.

This method of attacking a file sounds rather roundabout, but in fact is the way filing is done now. The difference is that a present search for a key word is done manually and may not produce the correspondence if the secretary who did the filing used a different key.

In a sense office automation is not as simple as pulling together data processing, word processing, and communication. The office is the center of decision making, too. But just as industrial automation has improved the functions of stamping, drilling, and assembling, so office automation should boost the efficiency of decision making and communication.

And, as in manufacturing, automation in the office need not mean a loss of jobs. Jobs will be upgraded so that secretaries will perform administrative tasks and mailroom clerks will become involved in data storage and retrieval.

The office of the future must be as much involved with people and their requirements as it is with equipment. Says Elserino Piol, manager of Olivetti's marketing and product planning department, "When we speak of the office of the future we are talking not so much about technology as we are about people. The human factor, people's willingness to adapt to new modes of behavior, is the unknown variable."

He feels that only through a step-by-step process can automation be applied to the office without meeting resistance from the work force, including the managers charged with implementing the changes.

How much change can we expect in the future? Franco de Benedetti, chief operating officer of Olivetti, says, "The answer lies deeper than technological applications and cost benefits, because the office is ultimately a people-oriented place. Technologically, penetrating the office continues to be an exercise in bridging the gap between promise and reality; the reality remains grounded in an aging, inert structure of patterned relationships."

In other words, the future integrated system can threaten an office's hierarchy. Sounding more like a psychologist than an equipment planner, de Benedetti comments, "A shift from a hierarchical structure to a polarization, with the elimination of intermediate groups and the replacement of higher groups by an oligarchy of specialists, would likely be prejudicial against middle-rank executives."

As for the hardware, the first step will be to link electronic typewriters, copiers, accounting machines, and magnetic filing systems via the office telephone system or a dedicated cable system. But, says de Benedetti, "these improvements in capacity will be useless if no improved access methods are available to the operator. The answer to this problem consists of data-base management systems, advanced structures, and natural inquiry languages."

For Olivetti planners, the term "future office" is something of an anachronism in that technically the future is now. A company study suggests that though unstructured work comprises 65% of all office activity today, the trend is clearly toward "organizing complexities." Not only is the economics of establishing an integrated office data-processing and -communications system becoming more attractive, but workers are becoming more familiar with the tools. Where in 1970 only 25% of the work force operated with computers in any way, it is expected that by 1985 more than 60% will deal with them and another 20% to 25% will have at least some knowledge of their function.

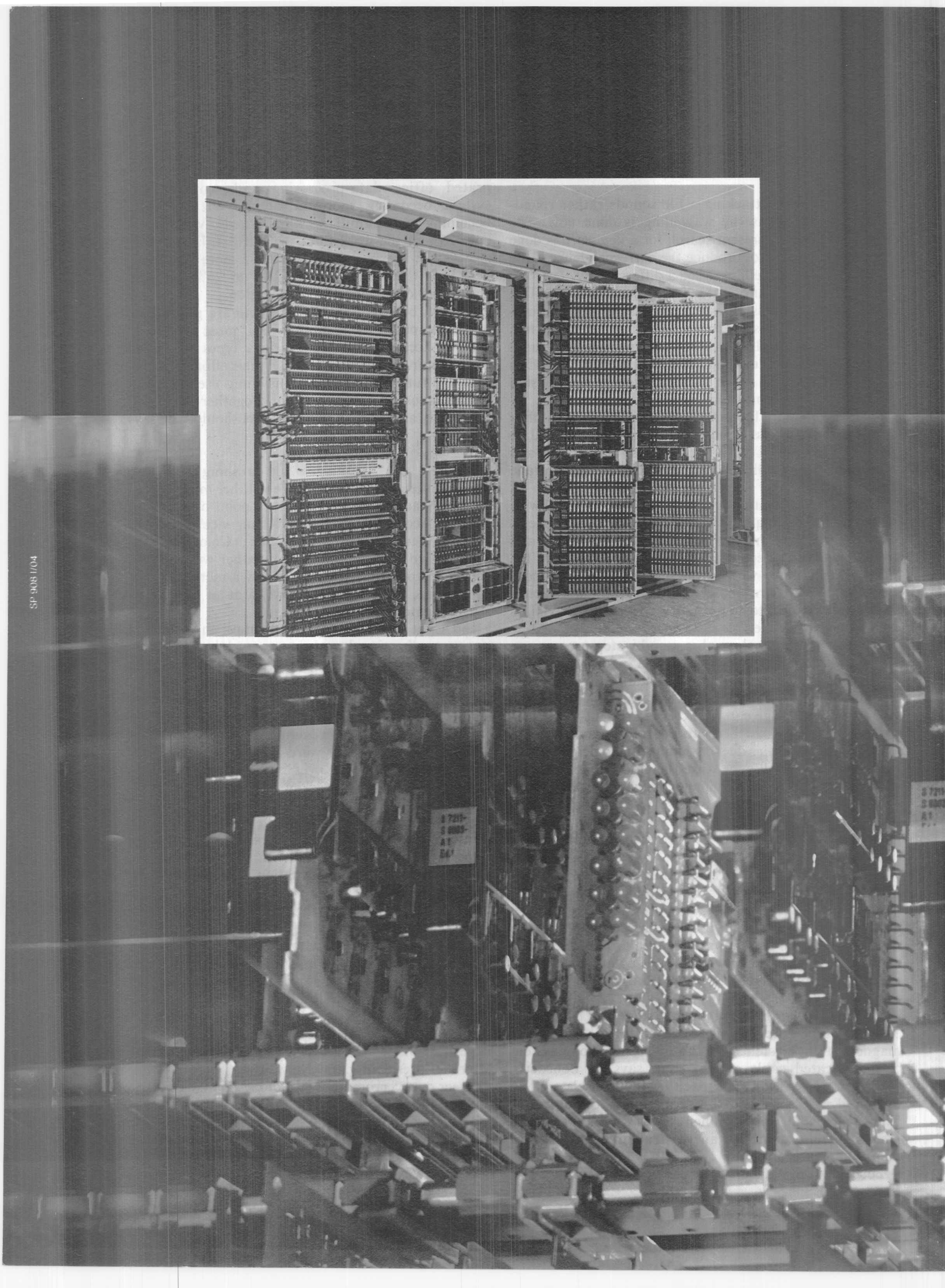
Olivetti believes that while people are growing closer to the computer, the computer itself must grow closer to people. According to Piol, various types of equipment manufacturers will have to mesh their efforts more closely in the future to avoid disillusioning users. "The electronics industry will have to work together as closely and coherently as we are implying others should," he says.

While outlining their thoughts on what the office of the future will be, most equipment producers and users are careful to point out what it will not be. According to David Klein, vice president for business development at NBI Inc., Colorado Springs, Colo., office automation will be neither word processing nor data processing nor even simply a merger of the two approaches, but rather a new form of more people-oriented automation.

But right now there are two camps: the office equipment suppliers anchored in a word-processing background and the computer hardware producers grounded in data processing. The word-processing companies argue that they understand the needs of the office better than the electronic digital-processing crowd. On the other hand, the data-processing manager in most companies outranks his or her word-processing colleagues and so exercises more sway over buying decisions. Clemenceau is said to have remarked that war is too important to be entrusted to generals. Office automation may prove too important to be left to the data-processing and word-processing managers and perhaps instead should become the direct responsibility of top management. The reason for high-level participation is that office automation is not going to emerge from the random purchase of standard office machines that will be strung together by some loose organizational procedures. Rather, it will have to be a coordinated effort involving the installation of hardware and communication links, development of software support, and employee training.

An example of such all-out commitment is the showcase system installed by Micronet Inc., a Washington, D. C., consulting firm. In operation since May 1979, this Paperless Office has attracted so much attention that Micronet president Larry Stockett has practically made a career out of promoting it. Among its many features is the fact that it represents the pooled resources and equipment of the 17 companies sponsoring the project.

The Paperless Office converts all incoming and original data into either electronic store or microfilm, depending on the nature of the material. All data can



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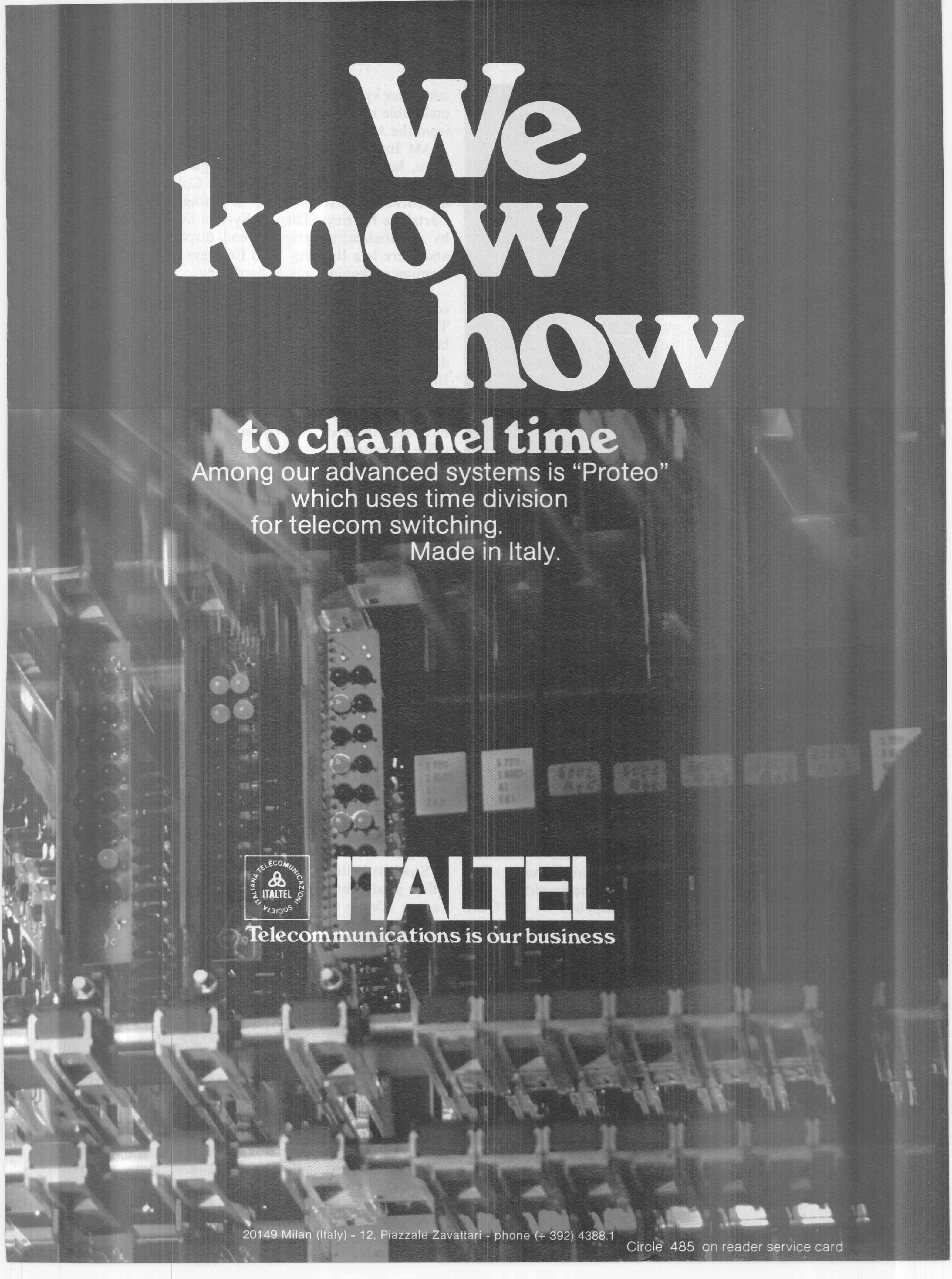
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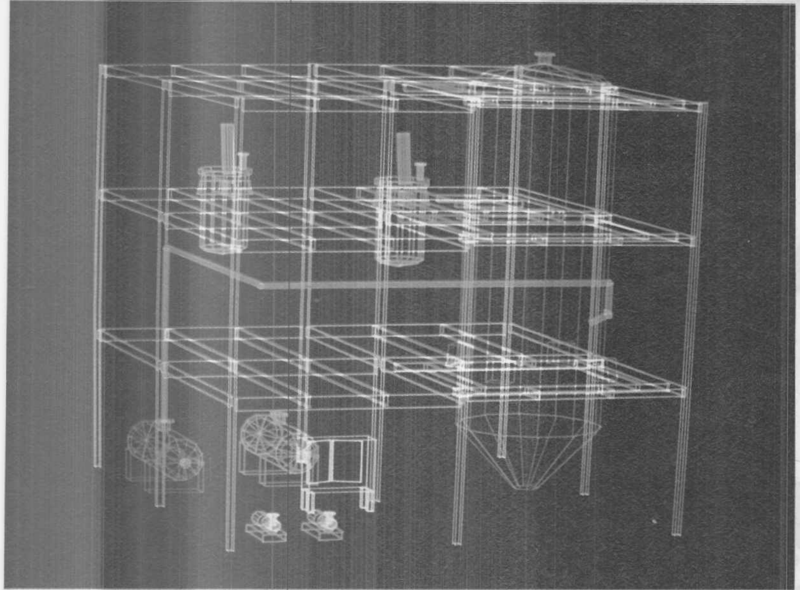


Floor plan. Using a computer, Evans & Sutherland has designed this chemical plant. The Multi-Picture System was developed to study the feasibility of designing plants with the aid of computer graphics. Its program was written to demonstrate the use of color in designing.

then be edited, indexed, sorted, retrieved, and converted into paper form, if necessary, to communicate with the "outside world." Correspondence coming into the office is usually stored in the computer system, while documents, catalogues, and other lengthy materials go on film where they can be called up for viewing by an automated microfiche retrieval system.

Information originating in the office often begins at a computerized Thought Tank System 193 from Dictaphone Corp., Rye, N. Y. It accepts dictation via a Touchtone telephone as well as desktop and portable tape-cassette recorders. The system can then distribute this dictation for transcription according to workloads and the priorities of the correspondence.

For word processing, the office has NBI's System 3000, a dual disk-storage unit capable of handling mathematical programs and communications. Data in the word-processing units can be stored on floppy disk or transmitted to a computer for storage or dissemination to other office terminals—again depending on the material.

Facsimile equipment has been supplied by the Qwip Systems division of Exxon Enterprises Inc., New York. And optical character-recognition equipment from ECRM Inc. converts typed copy into computer code.

Even with the minicomputers installed in the office, there is a need for time-shared computer services. Plessey Peripheral Systems Ltd. has installed both the mini- and microcomputer systems, while National CSS's Office Products division in Wilton, Conn., has provided the time-sharing capabilities, as well as access to an electronic mail network. Additional software comes from Microsystems Engineering Corp.

Both the paper and computer-generated data can be put on microfilm. San Diego, Calif.–based DatagraphiX Inc.'s AutoCOM converts the computer data into microfiche directly via an interface with the Plessey micro-computer system, including ... updatable microfiche by a System 200 Record Processor from the A. B. Dick Co. in Elk Grove Village, Ill.

AM International Inc.'s Bruning division, Cleveland, Ohio, has provided its OP 50 High Speed Microfiche Duplicator with OP 80 Automatic Collator for copying microfiche masters. The Bruning 95 Automatic Cartridge Retrieval Display System lives up to its name by automatically retrieving and displaying microfiche, and there is a Bruning 1830 Enlarger Printer for transforming microfilm back to hard copy.

The office also uses Access Corp.'s computer-controlled storage and retrieval system for microfiche. Thousands of fiches, representing millions of pages, can be indexed, filed, retrieved, and refiled in this unit. For displaying them there are terminals made by Realist Inc., Menomonee Falls, Wis. One of the problems with using both computer and microfilm storage is that it requires two displays at the work station; however, they have been incorporated well in the Hamilton Sorter Co.'s office furniture. The office also uses Zytron Corp.'s computer output microfilm service bureau network.

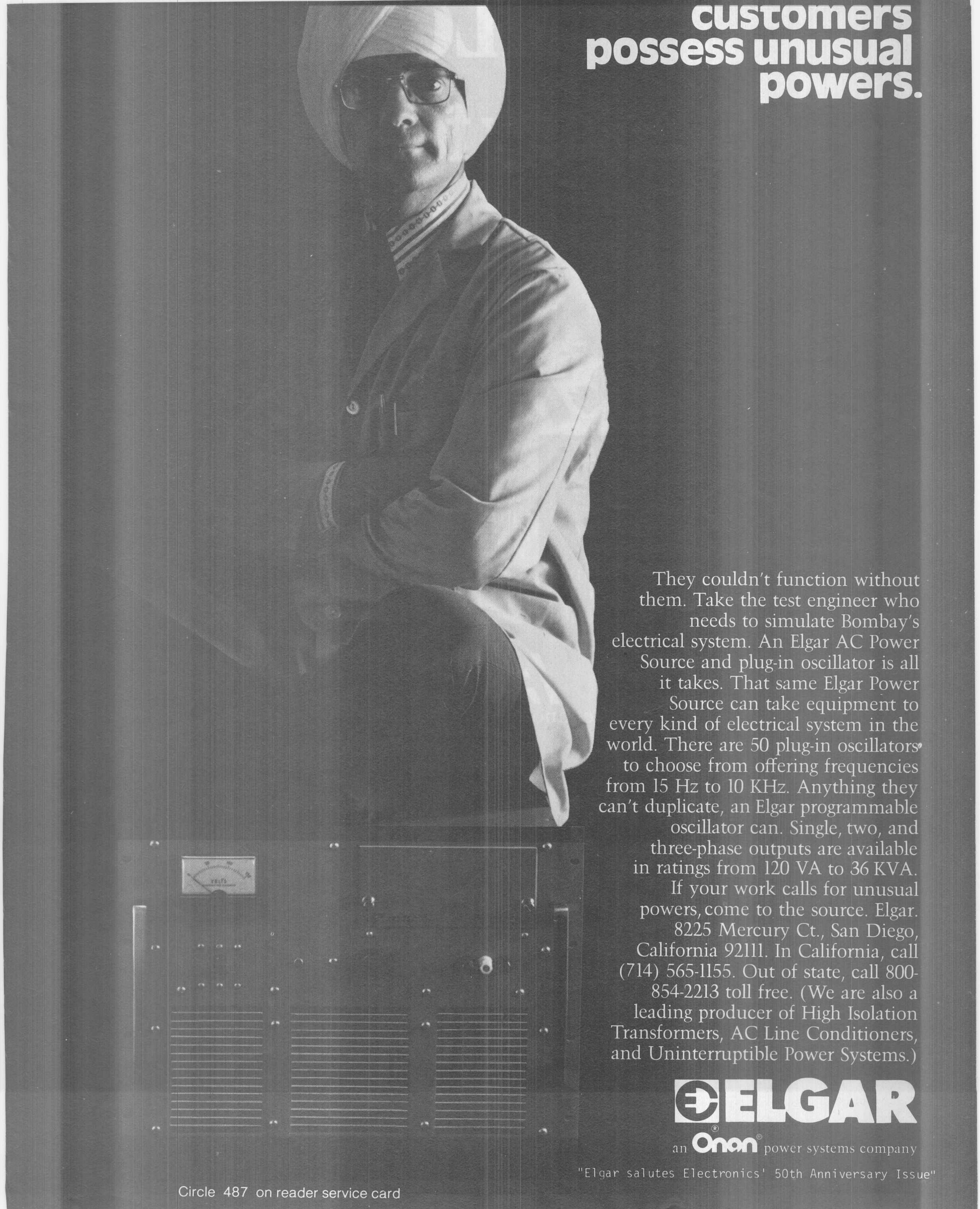
Stockett of Micronet emphasizes that the Paperless Office will never function without the use of some paper, but it goes a long way toward reducing the shuffle. Another plus in this system is that it automatically keeps track of worker output, something that has not been done very successfully in offices to date. It even monitors the telephones as part of the dictation system. In this way a manager can call in at any time and have correspondence recorded and prepared without being in the office.

There is also a means of recording what has been taken from the microfilm files and when the material is returned. This procedure not only provides a reading on how active the files are, but promotes security. Only about 3% of the files are kept in computer store at any point. The rest is on film.

What about taking work home? This office also has portable film viewers costing about $200 each, and an enormous amount of microfilmed information can be toted in these briefcase-sized units. The office uses 16 types of microfilm readers, depending on the needs of the viewer.

Stockett believes that past efforts aimed at increasing office productivity have too often focused on the wrong target. It's not the lower-salaried typists and clerks who need the attention, he says, but the high-salaried executives. "If the top manager can improve his or her efficiency by 5%, it can mean an increase on the bottom line of 30%. That easily pays for the system."

Back at the plant, electronics will continue to control more and more processes and machines. And it is solid-state technology that is bringing this industrial automation about. William C. Hittinger, executive vice president for research and engineering for RCA Corp., New York, says production-line activity will be measured and accessed on the spot—permitting rapid correction or adjustment—thanks to microprocessors and their ganglia of sensors. With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microprocessors used for controllers, robotics will flourish, he adds.

In 20 years there may not be an R-2/D-2 or a C3PO wandering around, but there will be significant advances in the capabilities of robots to distingush shapes and carry out complex series of instructions.

Also on the horizon is the automation of software production. Earle D. Jones, executive director of SRI's Advanced Development division, says, "You'll just feed the specifications into a computer and get back a program." Small demonstration programs toward this end are going on now, he points out.

One key feature of this concept is that the program is made to develop its own way to access remotely located data. Another is that the user accesses the program in plain language, not a computer language. "That 'front-end' language makes things exciting," Jones remarks. "We may see the worker become tightly coupled with technology."

The programs used to produce other programs have to be tailored to peculiar needs, though, and that is one of the roadblocks. It is impossible to package one program for a broad variety of users or systems.

In the next 10 to 15 years, machines will gain the ability to "see" meanings through the massive use of multiprocessors. For a machine really to understand what it sees or hears will take intelligent programs that are just beginning to be devised.

Regarding intelligent machines and robots, MIT's Dertouzos points out that a whole new approach will accompany the meeting of automation and the information explosion. "It's my contention that it [automation coupled with information capability] will reverse some of the impersonal and dehumanizing consequences of the Industrial Revolution," he states.

Here is how Dertouzos outlines his views in his recent book, "The Computer Age: A Twenty-Year View." In one of his imaginary scenarios, he has the consumer of the future buying a new pair of shoes at a center that will accurately measure his or her feet (filing the results automatically) with an instrument that simultaneously uses the information to code an "order card." Samples of shoes can be inspected, but the bulk of the selections will be looked over on a computer-driven color display. The consumer will pick a shoe model, request alterations to suit personal taste, and have the order card processed along with an automatic payment card.

The order card will program this equipment in the production shop to cut the leather to size and include the requested alterations. And after processing by other special-purpose machines, the shoes will finally be assembled by a robot. The whole procedure will take about 11 minutes, Dertouzos estimates, and its final product will be tailored to the individual, not to a standardized mass market.

"With a few exceptions and qualifications, the technology needed to support this hypothetical automated shoe factory is either here or almost here," Dertouzos declares. "Selection of parts in an automated stockroom has been demonstrated and implemented. Computer-driven sizing and cutting is already being done in certain sections of the garment industry. The conversion of foot measurements into two-dimensional patterns is straightforward in principle. Perhaps the least practical element is the automated robot that assembles a shoe."

Today's robots essentially repeat prearranged sequences or mimic a series of steps after a run-through. But they are severely limited by lack of sensory feedback and of knowledge specific to the task they must perform. To get greater flexibility into robots it will be necessary to equip them with sensors, particularly for sight, and with programs they can use to handle a variety of tasks.

The tough part will most likely lie in getting the robot to "understand" what its sensors are signaling. Computers help interpret images, but a general-purpose robot would also be required to recognize what action to take—to convert an interpreted image into a course of action, such as inserting a bolt.

Regarding automatic control systems, he observes that they, like robots, depend on sensors as they maintain a temperature or keep a plane on course in the face of disturbances or changes in direction.

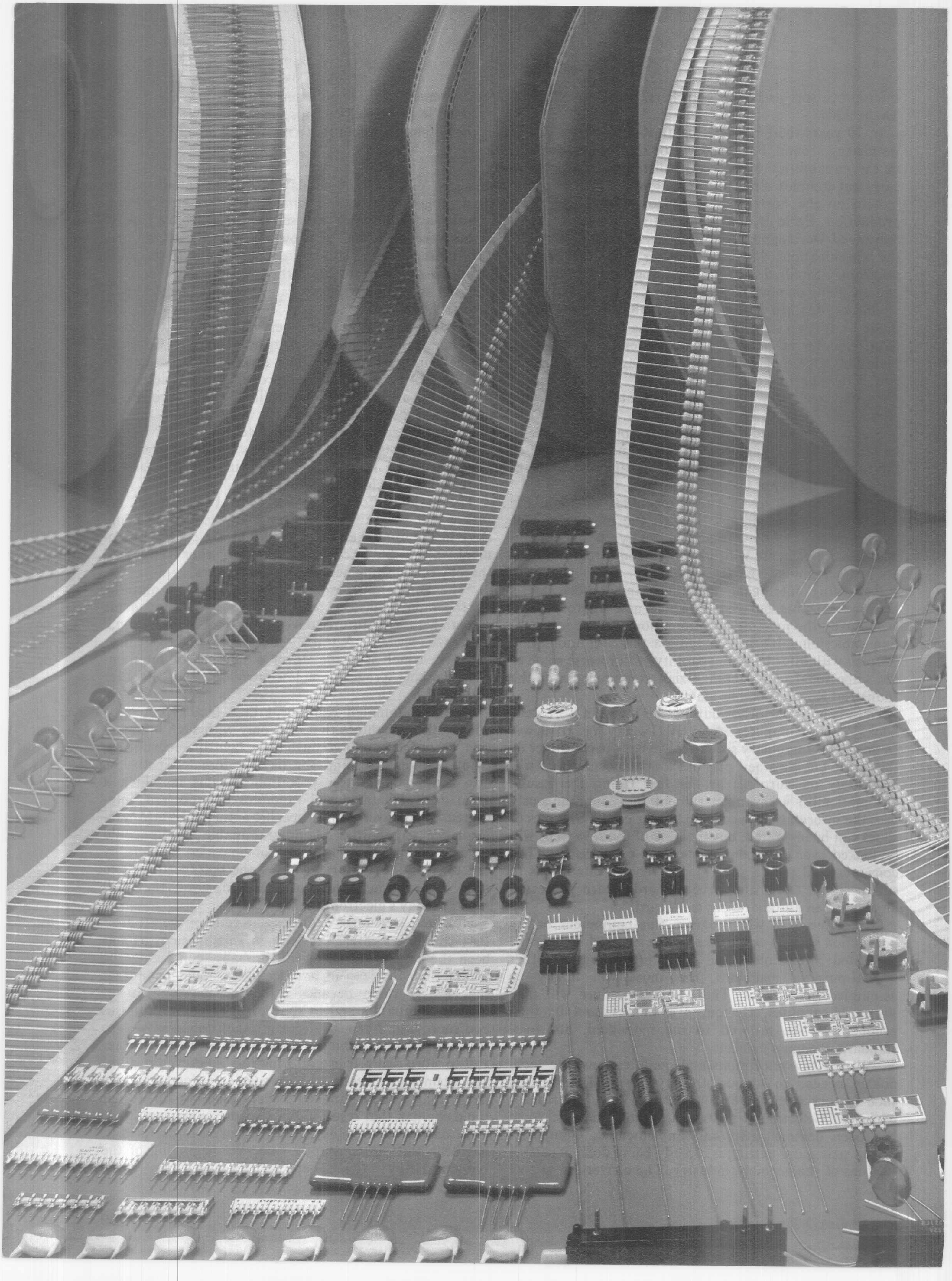
The major difference in the control systems of the future will be their use of computers to program and store information, he says. In addition, the control equipment will be able to communicate with other computers, thereby establishing networks of controllers.

"The general-purpose programmable robot and the microcomputer-based controller are two components essential to the future development of automation," Dertouzos writes. "A third is the distributed system or network, which is made up of a number of interconnected robots, programmable controllers, and computer systems."

To the automated equipment in a factory could be added other machines that deal only with such information as order handling, inventory control, accounting, plant maintenance, and the like. Automated networks also could control transportation systems in which a great deal of data must be monitored, processed, integrated, and converted into specific action. The cost/performance capabilities of programmable robots could become competitive with those of unskilled workers by the turn of the century. And as the cost/performance ratio of programmable controllers improves, they will replace today's electronic controllers.

However, Dertouzos cautions, "in spite of the promise that computers offer, the leap in imagination, as has been the case in the past, will probably continue to be bigger than the leap in practice. We should not forget that nearly three decades after the development of modern computers and in spite of intervening promises and successful demonstrations in other domains, we are still using these machines primarily to add and subtract and to store and retrieve information. And even if all of our technological problems are solved, it does not seem likely that workers and employers alike would accept rapid changes that result in massive unemployment."

Of course, labor, plus the skills needed to perform it, has been shifting constantly since the beginning of the Industrial Revolution. There will be such shifts in the



flexibility, economy, and individuali-zation of goods and services into our way of life, computer-based automation could provide the driving force that insures long-term progress," Dertouzos concludes.

Transportation in the year 2000 may not be much different from what it is today. The automobile should continue to be the principal way of moving people. Mass transit will still be important, with greater strides—as now—being made in Europe and Japan than in the United States.

As for space transportation, unless there is a national commitment—and challenge—equal to putting a man on the moon, manned explorations do not appear to be in the cards. However, there should be considerable activity in satellites to handle the growing need for communications during the information revolution described earlier.

By 2000, the impact of microprocessors will be felt in transportation, particularly in the automobile. At first glance, the typical car two decades from now should look surprisingly similar to the smaller cars of 1980. Underneath the fiberglass shell will be an internal-combustion engine powered by fossil fuel in liquid form.

Ford engineers say they expect two general classes of autos to be on the road: a small model for local use with room for one or two passengers and weighing about a third less than current compacts and a larger, cruising car for long trips. There should be room for smaller manufacturers to fill the gaps left by the major makers.

William Bourke, executive vice president of Ford Motor Co., Dearborn, Mich., explains that the American auto fleet will become "Europeanized," with most vehicles equipped with a four-cylinder engine. In fact, the conversion of American cars to the size and performance

Despite millions of dollars spent to develop such alternatives as diesel motors and improved batteries for electric motors, the internal-combustion engine will remain predominant. Less than 10% of the entire U. S. fleet, which may number more than 120 million by the year 2000, will be powered by other means.

Gould Inc., which has been involved in electric-vehicle development for five years, concedes that less than 5% of the fleet will be electric. "But that's a substantial number," notes Robert D. Carnahan, director of electrical and electronic research at this Rolling Meadows, Ill., firm, because a massive investment in tooling would be necessary to manufacture the hundreds of thousands of vehicles per year that even 1% penetration of the total new-car market would represent.

No matter what kind of power plant is under the hood, it will be controlled by a microcomputer, says Gene Karrer, vice president and general manager of Ford's Electrical and Electronics division. Even electrical vehicles that escape the Government's mandated emission-control and fuel-economy standards need precise electronic controls to conserve battery life.

Automotive engineers say the car of tomorrow will have a level of electronic sophistication common in aircraft today, which means a rapid growth in microcomputer applications. Most autos coming out of Detroit do not have a microprocessor, but that will change this fall when General Motors Corp. includes one on every engine of its 6 million new cars. It will be the mid-1980s before auto makers reach a sufficient IC parts count to support fully these tiny computers.

By then the average car will contain at least 50 ICs and top-of-the-line models will carry more than 100. Many Cadillacs and Lincolns already have half a dozen microprocessors controlling their engines, temperature

Coast to coast by tunnel

It sounds far-fetched, but a researcher for the Rand Corp. in Santa Monica, Calif., is working on a plan for a magnetic levitation propulsion system that would carry passengers from coast to coast—underground. Robert M. Salter, a senior physical scientist at Rand, points out that the concept—launching a train in a tube and propelling it electromagnetically—is sound but that the costs are staggering.

Others, too, think the idea has merit. The National Academy of Sciences is sponsoring a continuing look at Planetran, as it is called, and Rand has for some years kept the project at the ready, awaiting research funds.

When Salter talks about high speed, he means it. Planetran is seen—grab your hat—as able to hit maximum speeds of 14,000 mph, crossing the country nonstop in 21 minutes. A bidirectional, two-tube tunnel across the continent along a route envisioned by Salter would require a total of 5,440 miles of large tunnels perhaps 40 feet in diameter. This figure sounds outlandish, but he points out that about 8,000 miles of tunnels were drilled in the 1960s in the west alone and twice that distance by the 1970s.

How would the train run? Cars would contain cryogenically cooled supermagnets for levitation. Traveling electromagnetic waves in Planetran's guideways would oppose magnetic fields in the cars themselves in a way that would provide both support and forward or reverse thrust. For every car being accelerated in one direction, there would be one decelerating in an adjoining tube going the other way. Cars being decelerated would return electrical energy to the system, just as trolley cars did in the past.

The "waves" of energy would then move the car along the way an ocean wave propels a surfboard. The difference is that the extremely high speeds will require very precise controls to maintain the car's stability. In the past, the computers required to handle this task would have taken up all the space in the car, but today's microcomputers make the concept more feasible.

"Is the Planetran far-fetched?" Salter asks rhetorically. "To gain proper perspective, it's instructive to look back over the past 100 years in transportation and see how far we've come. Present travel and freight systems have proliferated without much attention being given to their relationship with integrated plans for the future. Without inspiration, we could have just more of the same in 2080."

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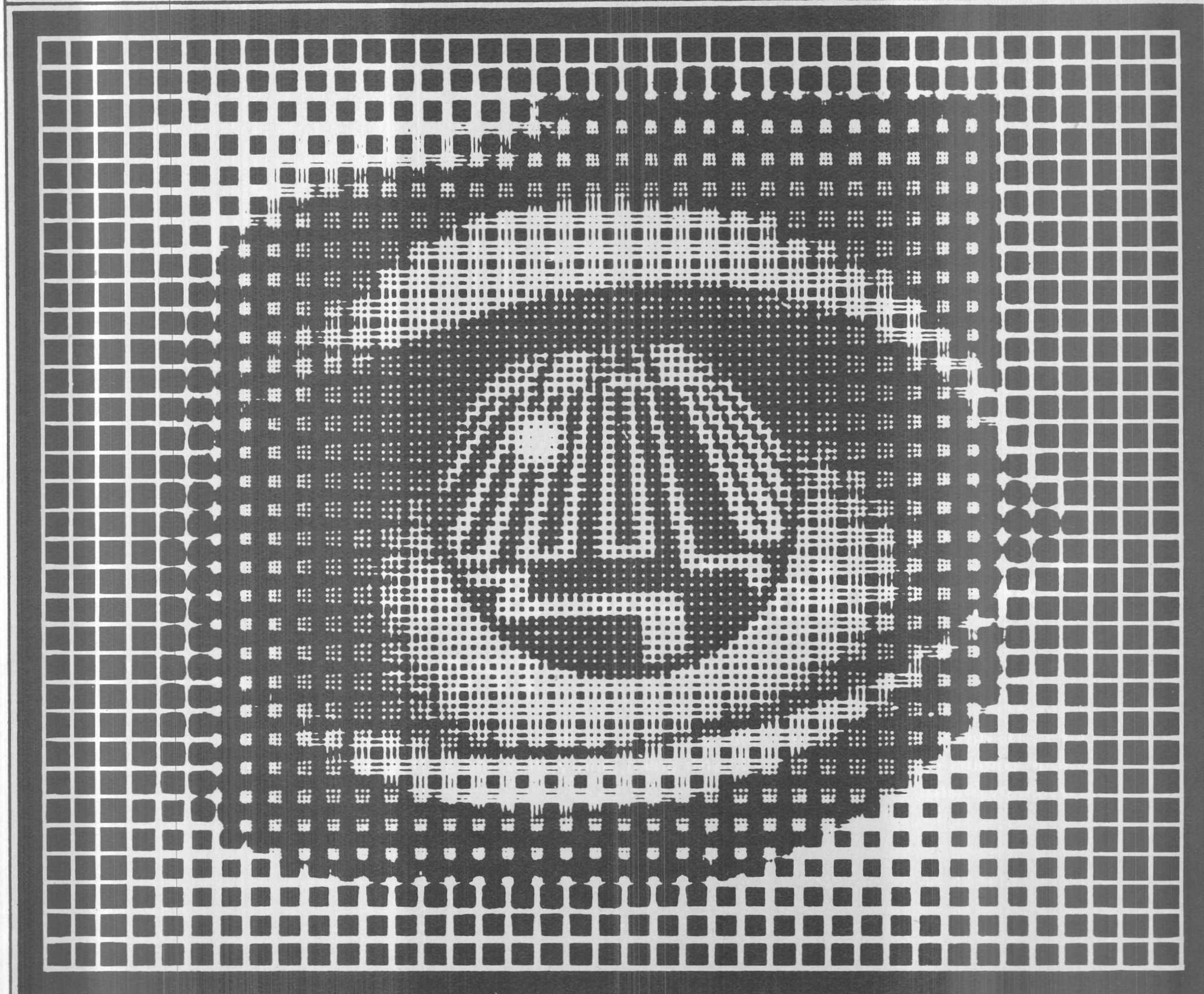

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On the road. Transportation in the year 2000 will still depend largely on the automobile. But like this specially built Aston Martin, there will be a great use of electronic controls and displays. Several microcomputers will be installed in each car for a variety of functions.

controls, radios, and instrument panels. And automobile engineers are predicting that as cars become smaller (downsized, as they say in Detroit), electronic features will replace comfort as a key selling point. The increase in popularity of high-priced automobile sound systems is the first evidence of the new attraction that quality audio now has for even the average driver. Electronics will be used as a marketing edge, according to Robert Oswald, executive engineer for instrumentation and features at Ford—a man who has a stake in his own prediction.

Though the number of electronic functions will grow 20% or more, the parts count will stabilize in the mid-1980s and decrease by 2000. For example, the top-line Cadillac this year has 12 large-scale integrated circuits, but Frank Jaumot Jr., director of advanced engineering at GM's Delco Electronics division in Kokomo, Ind., predicts it will have about 10 by 2000.

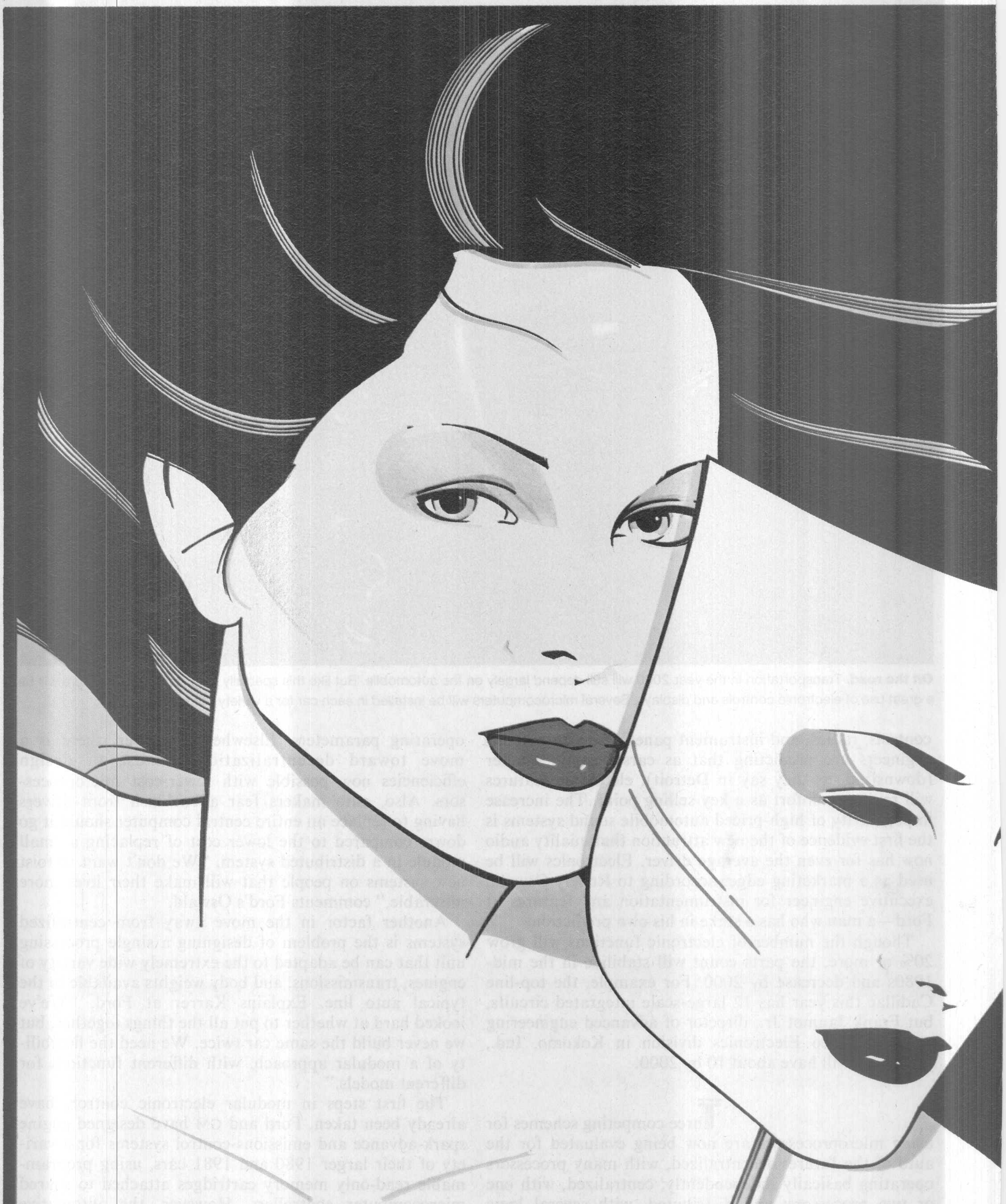
Three competing schemes for using microprocessors are now being evaluated for the auto of the future: decentralized, with many processors operating basically independently; centralized, with one or two processors; and distributed, with several logic centers all using shared inputs from a variety of sensors in the engine, transmission, and exhaust.

GM, for instance, has established as a corporate policy that each of its cars will have a single computer control center, including a memory section storing a data base of operating parameters. Elsewhere, however, there is a move toward decentralization because of design efficiencies now possible with lower-cost microprocessors. Also, auto makers fear a backlash from drivers having to replace an entire central computer should it go down, compared to the lower cost of replacing a small module in a distributed system. "We don't want to foist new systems on people that will make their lives more miserable," comments Ford's Oswald.

Another factor in the move away from centralized systems is the problem of designing a single processing unit that can be adapted to the extremely wide variety of engines, transmissions, and body weights available in the typical auto line. Explains Karrer at Ford, "We've looked hard at whether to put all the things together, but we never build the same car twice. We need the flexibility of a modular approach, with different functions for different models."

The first steps in modular electronic controls have already been taken. Ford and GM have designed engine spark-advance and emissions-control systems for a variety of their larger 1980 and 1981 cars, using programmable read-only memory cartridges attached to shared microcomputer controllers. However, the automotive electronic control systems will do more than conserve fuel. They will alert driver and mechanic to impending failures by comparing current operating data with history to pinpoint a decline in performance.

Low-cost mass memory is coming to the auto industry



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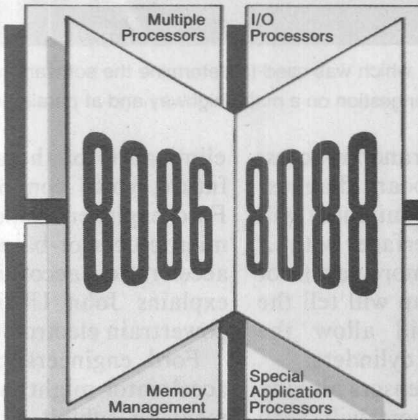

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Circle No. 497 for information

Controlling the wheels. At a traffic control center, which was used to determine the software needs of a computerized system designed by Sperry division of Sperry Corp., a controller tracks congestion on a major highway and at parallel intersections to divert traffic.

as well. Ford already is using a 64-K random-access memory from Motorola as part of its on-board diagnostic system, and future generations of this equipment will have special input/output ports to interface with a mechanic's test instruments to measure more facets of engine performance. Thus, the same system will tell the drivers their fuel consumption and will allow the mechanic to check specific spark plugs and cylinders.

Besides the engine and exhaust-system sensors already incorporated into electronic controls, others will keep track of the transmission and the interior of the car. Torque and atmospheric sensors and others will be used to monitor spark ignition, fuel injection, and other operations, predicts Patrick Reciputo, assistant chief engineer for automotive electronics at Delco. "It will be an honest-to-goodness closed-loop system."

While engine-control designers are anxious to link operating functions in the engine, exhaust system, and transmission, others are working on more electronic displays for the driver. But perhaps the most striking change in the passenger compartment will be the elimination of the accelerator pedal—in the car of the future, voice commands will determine speed, predict Ford engineers. Upon receiving the speed instruction, a microprocessor-based engine-control system will begin acceleration according to a fuel-conservation optimum, explains John Ullrich, a Ford executive engineer for powertrain electronics engineering.

Ford engineers conjecture that the voice-controlled accelerator might eventually be required by the Government to inhibit drunk driving. If the driver's voice sounded slurred, the car would not function. A key-based override would probably be necessary, however, to allow someone else to operate the car.

The instruments in the driver's compartment will probably disappear in time, to be replaced with an electronic display, perhaps a cathode-ray tube. Besides warning about possible equipment malfunction and maintenance needs, the display might be used as a road map generator, engineers speculate.

Oswald of Ford estimates the CRT will cost $100 and be backed by 256 kilobytes of memory for route guidance, and it may include trending or graphics capabilities to indicate maintenance requirements. Instead of

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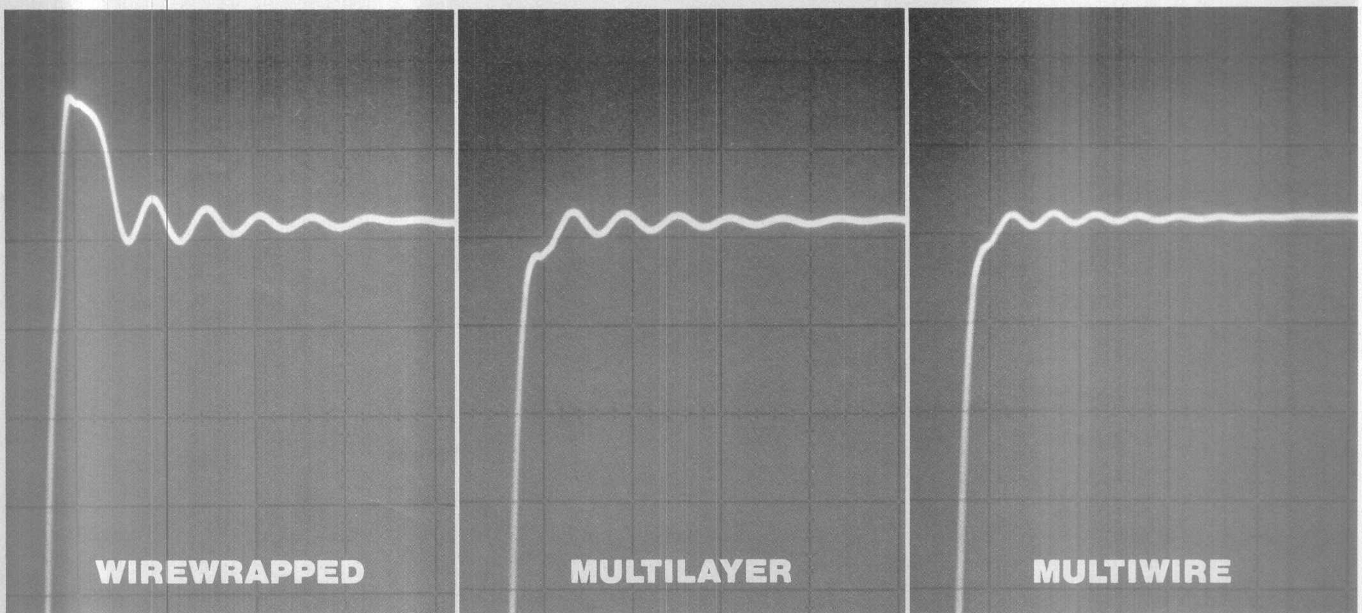

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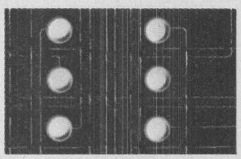

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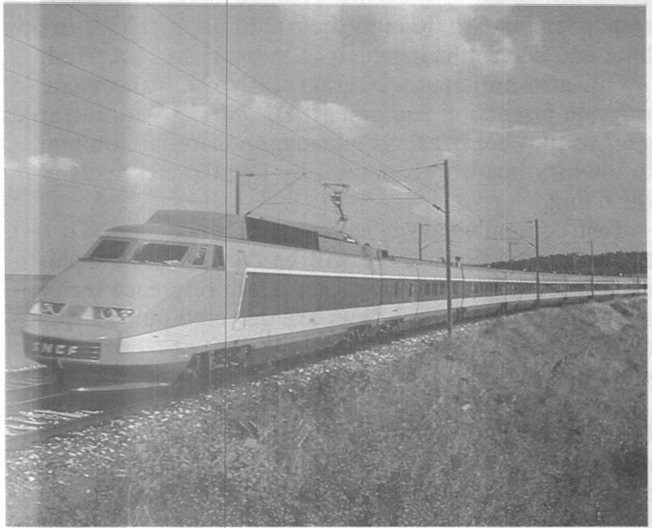


Vite, vite. The French National Railways has launched a new railway capable of over 160 mph. An elaborate electronic system has been installed to handle the switching of the trains as they rush along. The system also controls the braking action.

Magnetic train. Researchers in Germany have been experimenting with a railroad that would operate on magnetic levitation. Vehicle-mounted magnets lift the car from the rails and a linear induction motor propels it at speeds as high as 400 kilometers an hour.

being scheduled according to time, he says, maintenance will be requested by the engine-control computer on an as-needed basis.

Collision-avoidance systems (CAS) using radar signals have been developed over the years, but engineers are skeptical about them. Will drivers trust such a warning—in other words, will the system be reliable enough to gain the driver's confidence? Unless there is a Government requirement, CAS will be accepted only very slowly. In any case, most accidents involve cars moving in the same direction in the same lane.

Not to be overlooked are the entertainment and comfort functions of automotive electronics. The entertainment center in a future car will be similar in quality to home audio systems, and optical playback units reading digitally recorded sound will be available.

Another form of sound recording will probably be solid-state memories mounted in cartridges to play back audio. Comments Les Wilkinson, general supervisor of communications development at Delco, "We've not seen the impact of inexpensive memories yet."

Electronics will also be used to replace direct driver controls. Instead of a driver-altered thermostat to control heating and air-conditioning, Wilkinson expects "adaptive electronics" to take over. Sensors will detect increased sunlight and temperature in the passenger area and automatically compensate for it. De-icers and windshield wipers will be similarly responsive to sensor-detected conditions.

Despite poor performance and lack of funds to date, computerized traffic control continues to be an idea that occupies transportation planners. One such system is the Integrated Motorist Information System (IMIS) being designed by the Sperry division, Great Neck, N. Y., of Sperry Rand Corp. for the northern traffic corridor on Long Island, N. Y. IMIS extends from the New York city limits into Suffolk County—a heavily traveled section.

Components of the 35-mile-long system include a central computer, electronic sensors buried at half-mile intervals in the roadways, variable message signs, and computerized traffic signals at key entrance ramps to the expressways, as well as at intersections on parallel arteries and major connectors. Also included will be motorist-aid call boxes at half-mile intervals and near-field radio transmitters to advise motorists of conditions ahead.

The task is to detect congestion quickly enough to divert traffic before a major tie-up develops. Weighing information from the sensors, the computer may someday control various output devices to regulate traffic. Depending on the type of computer finally chosen for the system, it could serve as a central control for the call boxes, notifying the police of congestion and breakdowns and funneling requests for aid to towing services.

The energy supplies of the future will of course be the major influence on public transportation. There is increasing awareness in communities with underdeveloped transportation systems that mass transit is imperative. But all communities are facing a similar dilemma—how to increase transit revenues while lowering costs.

"This means moving to automation as quickly as possible, for only then can the problems of manpower cost, system efficiency, and high passenger volume be accommodated," says Raymond L. de Kozen, vice president of marketing for Cubic Western Data Corp., San Diego.

This is not to imply that mass transit will become entirely computer-operated; rather, the motorman and conductors and so on are to be reassigned to "mainstream" jobs—if their unions are willing to be similarly "reassigned." The technology exists to assure self-ticketing and automatic entry and exit of passengers, with

accounting tied to the system via distributed processing networks.

Actually, Cubic is involved in automatic ticketing for a variety of applications. As more mass transit systems apply this technique to existing or new installations, it will likely spread to airlines and interurban buses. Automatic ticketing may find a role in the entertainment industry as well.

Though passenger rail service in America today is in a depressed state, long-haul freight trains are still profitable. And the railroads have been looking to electronic technology to help solve some of their problems.

"There's a lot of room for microprocessors in rail equipment," declares Ross T. Gill, manager of Research and tests for the Southern Pacific Transportation Co. in San Francisco. For example, "we want to give the engineer more information in the cab, including the forces that are operating on the train, so he can avoid hazardous situations."

One concept in research and development is a microprocessor-based cruise control for diesel locomotives similar to that used in automobiles. These would be add-on black boxes that would optimize throttle settings and fuel consumption and would be based on the type of locomotive and size of the train.

Southern Pacific is looking at diagnostic tools that verify an engine's electrical system, at on-board self-test units, and at modular electrical components that can be easily tested and replaced. Also in R&D is a remote air responder that would read the condition of the air-brake lines and determine in which car a break has occurred.

Gill also anticipates a great deal of advancement in wayside inspection equipment. His carrier uses infrared gear to spot hot bearings on cars, and similar equipment to identify hot wheels caused by imbalanced loads is in the offing.

Test equipment on wheels will progress, too. To test track specifications, there will be cars of more sophisticated geometry employing laser-beam reference technology, Gill predicts. Rail flaws are detected now at speeds of 20 miles per hour; the goal is to do it at 60 to 70 mph with ultrasound or other technologies.

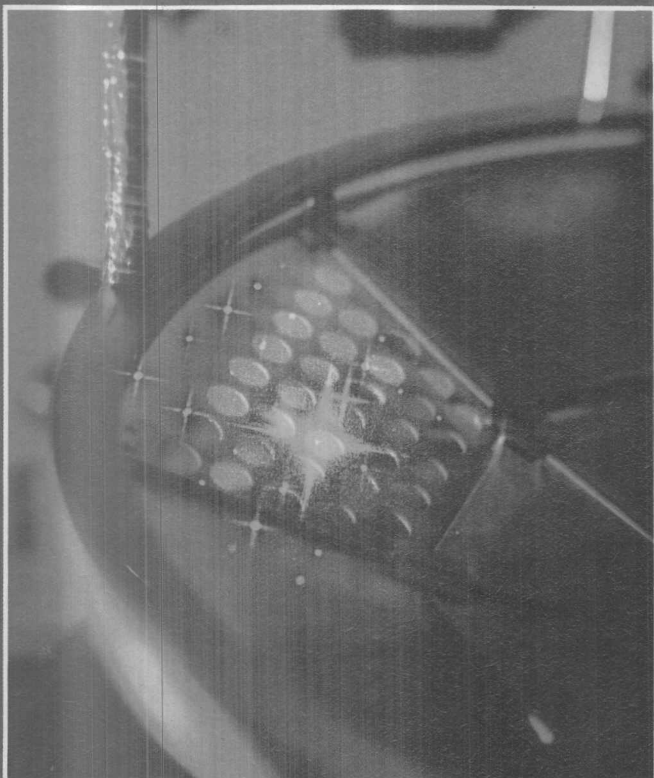
To get a real picture of the trains of the future, however, one must examine the plans of the railroads overseas. Unless something catastrophic happens in the next year or so, the French National Railways (called SNCF) will be running the world's fastest track service starting in 1981. That's when the SNCF plans to begin full-fledged passenger service with its Train à Grande Vitesse (TGV). It will cover the 266-mile stretch between Paris and Lyons in two hours, hitting top speeds of 162.5 mph and averaging 132.

This tops the pace set by the New Hokkaido line in Japan—though the Japanese are also working on increasing the speeds of the famous Shinkansen, often called the Bullet Train.

Although it clocked over 200 mph with an experimen-

Space travel. IBM test engineers check out the instrument panel in the Space Shuttle Orbiter cockpit simulator at NASA's Johnson Space Center. There are two programs: the system services that manage the overall computer operations and their applications programs.

Building with the future in mind successful in world-wide markets



Facts about Iskra

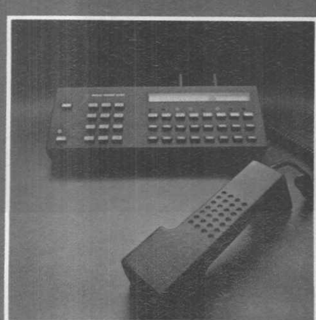
The score US$ 1.233 billion of total revenue per year has brought Iskra to the 58th place in the world's electronics industry, to the 16th in Europe and to the number one place in Yugoslavia. The average exportation rate througghout the last 15 years grew steadily — even in hard times — gaining 27% annually.

The purchasers in several countries extending over four world continents bought for more than US$ 120 million of Iskra's goods and services in 1979. The major part of the exported goods went for the developped countries of western Europe and USA, 27% were destined for developping countries and 23% of its products were sold to the countries of Comecon.

1. *Testing of electronic telephone exchanges units.*
2. *Telephone "Isicom super".*
3. *Factory for the production of automatic telephone exchanges. This is one of the 60 Iskra's factories in Slovenia.*


1

3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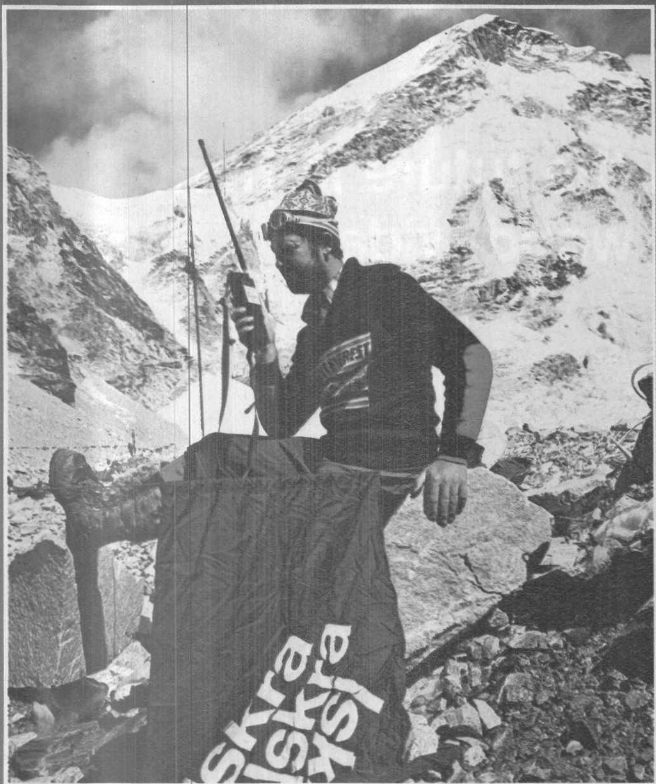
Complete systems and top make products covered 55% of the exported value, industrial cooperation reached 20% while the engineering services, technology transfer and know-how were represented by 5% of the total export value.

However, the share of sold or transferred know-how abroad takes greater dimensions, since it is included in the sales of complete systems as well as in international cooperation activities.

Iskra - an international electronics company

Significant developments in research, technology and business - Significant developments in research, technology



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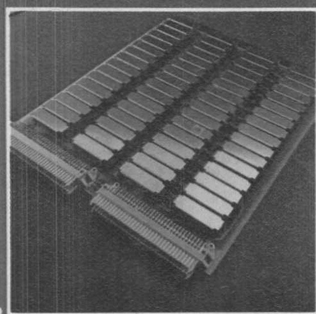
4. *Iskra's radio-relay equipment used by yugoslav alpinists on Mt. Everest.*

Some facts about Iskra's relations with the world

The Iskra Co. owns 24 trading companies, production companies, and representative offices in 17 countries all over the world. The quality of Iskra's products and services is known by its demanding business partners, buying parties and users in New York, Stuttgart, Milan, Paris, London, Biel (Pieterlen), Prague, Warszaw, Berlin, Bucarest, Cairo, Tehran, Caracas, Brussels, Mannheim, Quito, Barcelona and hundreds of other places. The news about Iskra reached as far as Mt. Everest peak as well as many a spot of the world where man seldom sets his foot.

However, in spite of the expansion of Iskra's activity all over the world, the number of biggest importing countries of its products and services is itself limited. These are the states where Iskra Co, has established its own foreign trading firms with steady and long-lasting relations concerning business, technical and scientific collaboration as well as permanent industrial cooperation together with other, more advanced ways of international exchange.



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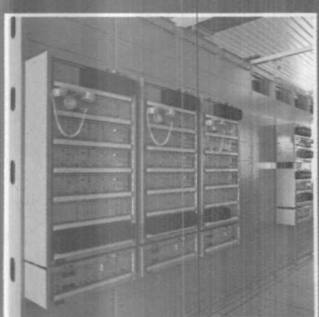

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5. *Telegraph equipment for remote control and supervision.*
6. *Module.*
7. *Computer center of Maribor University, delivered by Iskra.*
8. *Automatized marshalling yard "Zalog".*

The company has some 29,000 employees including 1,600 research and development engineers in 80 factories, research, marketing and other organizations, and the most up-to-date technologies to work with. In its development, Iskra is oriented toward tomorrow's activities which go far beyond the traditional limits of electromechanics and extend to the widest application of electronics with priority being given to the promotion of the development of communications systems and equipment, computers, automation (of traffic, power generation and power distribution, and automation of industrial processess), security and protection systems and equipment, and engineering activities. All to ensure that every project we handle comes within schedule and budget requirements and meets performance and client expectations.


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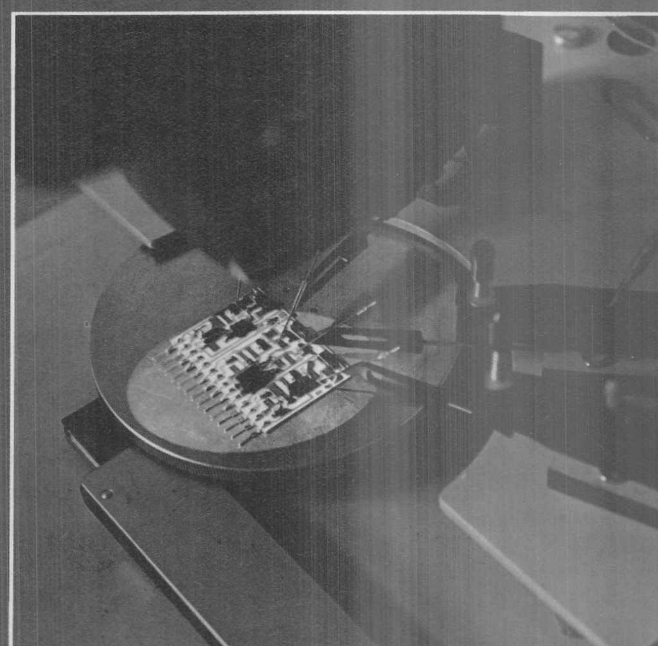
13. *Kilns with regulated temperature and atmosphere for firing thick film layers.*



9. *Iskra Limited trading company head office in U.K.*
10. *Laser communication device.*
11. *Various laser equipment made by Iskra's up-to-date technology are well known in world markets.*
12. *Iskra company head office in Ljubljana, Yugoslavia.*


13

From its wide production programme Iskra invests most in developing the following segments:

Micro-electronics - with all technological variations including thick and thin film technology, the majority of thin films is made in MOS technology. Semiconductor materials and components.

Business and data processing computer systems and programming equipment, micro computers and micro processors.

Optoelectronics - Development of telecommunication components as optically coupled relays. Holography, mainly for use in memory banks. Optoelectronic for measuring purposes.


17

Integrated telecommunication systems, based on digital technology as PCM Multiplex and PCM communication equipment.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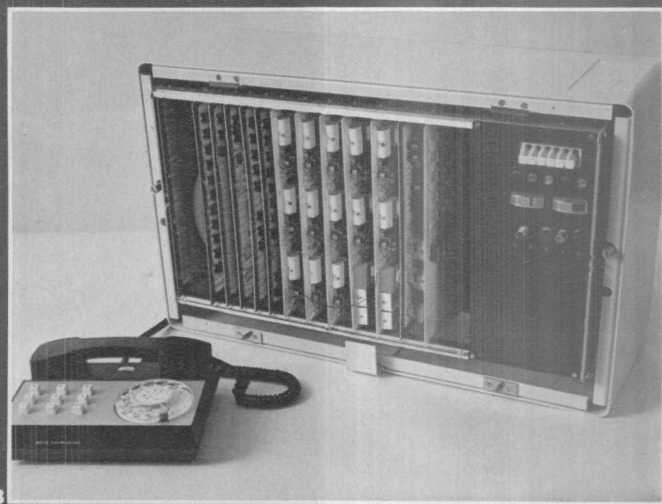
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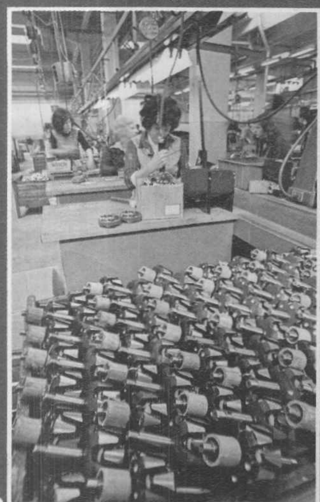
Engineering activities - Engineering for road and railway automation, for automation of industrial processes, electric power generation and distribution, engineering for communications systems and equipment, for watthour meters, consumer goods and various others in the specialised field of technology. Emphasis will be placed on all research and development activities within the company.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19

14. *Calibration stand for watthour meters. These type of stands are also exported to Tunis.*
15. *Production of TV sets.*
16. *Production of electrical automobile parts.*
17. *EPABX 300 type electronic telephone exchange in Holiday Inn hotel in Ljubljana.*
18. *EPABX 16 electronic telephone exchange.*
19. *Computer center of an international electronic telephone exchange.*

Iskra

For further information, please contact our head office in **Yugoslavia:** Iskra Commerce, Trg revolucije 3, 61001 Ljubljana Yugoslavia, Telephone-international: 38 61 324 261, Telex: 31-356 yu iskexp - or our trading companies and representative offices in **Czechoslovakia Iskra,** Lazarska 5, 11000 Prague, Tel: 202771 - **Egypt: Iskra Cairo,** 34 Adly Street, P. O. Box 206, Cairo, Tel: 747695 - **France: Iskra France S. A.,** 354, rue Lecourbe, 75015 Paris, Tel: 5540427 - **GDR: Iskra,** Hermann-Materenstrasse 46, 104 Berlin, Tel: 2828322 - **Germany: Iskra Elektronik, GmbH,** Furtbachstrasse 2b, 7000 Stuttgart 1, Tel: (711) 603061 - **CEFRA, GmbH,** Ungererstrasse 40, 8000 München 40, Tel: 392061 - **Italy: Iskra Elettronica Italiana, S.r.l.,** Piazza de Angeli 3, 20146 Milan, Tel: 4980036 - **Iran: Iskra Tehran,** 9th Street No. 6, Maydan Sanai, Tehran, Tel: 826765 - **Poland: Iskra,** Swietokrzyska 36m 15, Warsaw, Tel: 201253 - **Romania: Iskra,** Str. Visarion nr. 6, Bucharest Tel: 502675 - **Switzerland: Iskra Electronics AG,** Stalden 11, CH 45000 Solothurn - **united Kingdom: Iskra Limited,** Redlands, Coulsdon, Surrey CR3 2HT, Tel: 6687141 - **Perles (UK) Limited,** Rands Lane, Industrial Estate, Armthorpe, Doncaster, Yorkshire, Tel: (032) 832831 - **USA: Iskra Electronics Inc.,** 8 Greenfield Road, Syosset, N. Y. 11791, Tel: (516) 3642616 - **USSR: Iskra,** Mosfiljmovskaja 42, Moscow, Tel: 1478403 - **Venezuela: Eurocommerce S.A.,** Apartado 68 901, ALtamira, (Officinas 19 & 20, Edificio Beca, Chacaito), Caracas, Tel: 728821.

Circle 506 on reader service card

tal train several years ago, the SNCF feels that the TGV will be fast enough for some time to come. Because of the high cost of construction and new rolling stock (about $1.6 billion), though, there will probably be no extension of the TGV to the rest of France for the foreseeable future.

Naturally, electronics will have a key role in the TGV. A wired-logic control will supervise the engineer at first, but SNCF expects to have microcomputers in some trains by the mid-1980s. "They are essential on lines where headway between trains is less than a minute," explains Jean Plantureu, an executive in SNCF's General Studies and Research division.

At speeds of 162 mph, conventional block signals would be mostly a blur to the TGV engineer, particularly if visibility is poor. So the signals are in the cab; as the train enters a display section, an indicator shows which of five preselected speeds—from 162.5 mph to 0—is authorized for that block. The wired-logic control supervises the engineer, warns him when he is going too fast, and applies the brakes automatically if the speed gets out of hand.

Meanwhile, transportation researchers in Germany have begun experimenting with an entirely new means of railroad locomotion called magnetic levitation, or maglev for short. In maglev, vehicle-mounted magnets lift the car away from the rails, thus providing a gap over which it can be propelled by a linear induction motor at more than 400 kilometers per hour (about 248 miles per hour).

To ensure stability, the gap must be kept at a uniform width, and that task is best done by electronic controls.

West Germany's efforts in maglev date back to 1969, when the Bonn government commissioned a large-scale study of new, high-speed train systems. The efforts are now concentrated on a seven-company consortium called Magnetbahn Transrapid, headed by the aerospace firm Messerschmitt-Bölkow-Blohm GmbH (MBB).

Using electromagnetic suspension principles, the consortium's engineers have thus far built a number of experimental carriers, one of which—an unmanned 8.8-ton, 8.5-meter-long instrumentation carrier—reached a speed of 401.3 kmph (about 249 mph) on a 1,300-meter track in 1976. Last summer at the International Transportation Exhibition in Hamburg, a 36-ton, 26-meter vehicle, designated Transrapid 05, shuttled passengers at 90 kmph (about 56 mph) along a 908-meter, pillar-supported track linking two railway stations.

The consortium is now planning a 31-km test track in a sparsely populated area in the northwest of Germany where, by 1982, a follow-up model will be tested. Designed to travel at speeds between 300 and 400 kmph (about 186 to 248 mph), the Transrapid 06 will initially consist of a 100-passenger section and later be expanded to a two-section vehicle.

Such trains will first serve as airport shuttles and the like. By the end of the century, however, maglev trains may be traveling over the first sections of a European rail network. In fact, the experts are investigating the feasibility of a Frankfurt-to-Paris maglev link. The advantage of this type of train in energy conservation, speed, and ease of construction are obvious.

The electromagnetic suspension system consists of support and guidance magnets on the vehicle and iron rails on the track. The support magnets are arranged so that, when switched on, they attract the vehicle vertically toward a set of rails. The guidance magnets act on another set of rails running along the side of the suspension system to keep the vehicle stable laterally. When the magnets are off, the vehicle rests on a spring-supported glide system, which would also act as a support in the event of magnet failure.

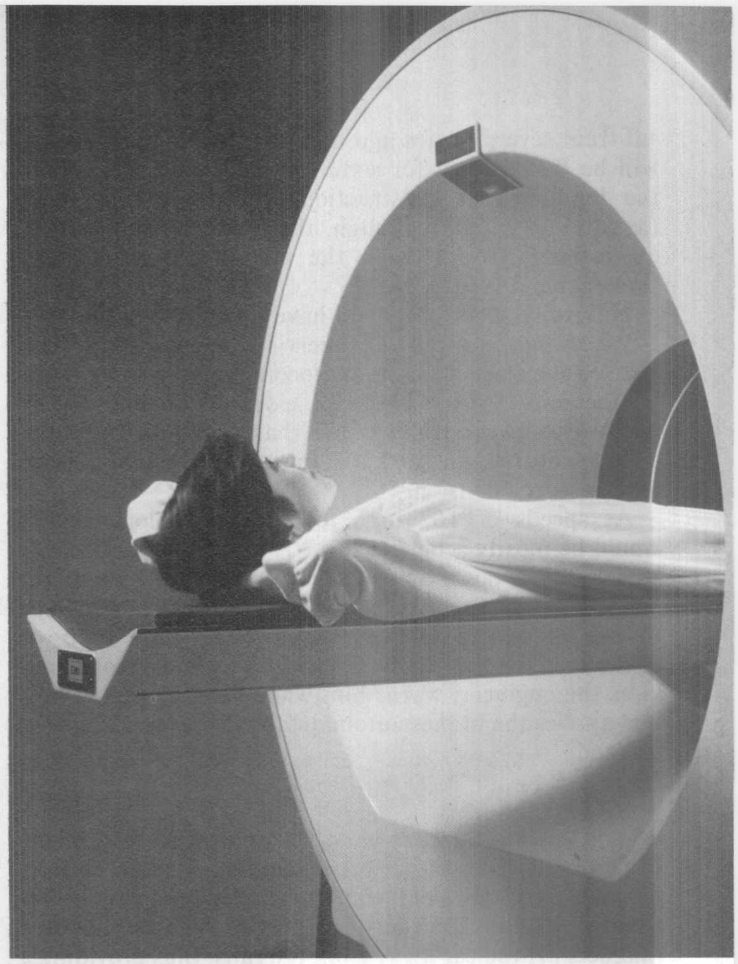
Propulsion is achieved with a linear induction motor, one part of which is mounted on the vehicle, the other along the track. Unlike rotating electric motors, linear induction motors provide translatory motion. They serve not only as propulsion units but also as dynamic contactless brakes. Frequency converters control both propulsion and braking.

The magnet-to-rail gap over which the train travels must be kept as narrow as possible—typically 10 millimeters—to keep the magnets as small as possible. This requirement puts exacting demands on the electronic controls.. Inductive sensors integrated into the magnets will keep tabs on the gap. Using as criteria the magnetic-field variations resulting from shifts in distance between the magnets and rails, the sensors can determine the gap to within ± 0.1 mm. To determine the effects of wind and other forces on the vehicle, and hence the gap, the suspension system employs capacitive pickup acceleration sensors. The outputs of both sensors are fed to a control system that adjusts the voltage on the magnet coils so that the magnetic field reaches the level producing a 10-mm gap.

A computer in the vehicle monitors both drive and guide equipment, checking current through the coils and the gap width and delivering the proper signals to the propulsion mechanism. Computers installed in command and signaling facilities along the route monitor the train's operational status. Communications between train and trackside installations will be via a slotted waveguide running along the track; a train-mounted antenna protruding through a slot into the waveguide will establish the link.

"With no novel components and virtually no fundamental research work required, implementing the system is basically an engineering job," says Eveline Gottzein, head of MBB's Control Dynamics and Simulation Department. Research on maglev is also under way in Japan, France, and the Soviet Union, and it has been proposed in the U. S. as well (see "Coast to coast by tunnel").

Though the science-fiction community will of course be disappointed, many electronics executives who graduated from the space program of the 1960s do not expect there to be much in the way of manned space flights in the coming two decades. Observes Thomas Markley, Raytheon Data Systems president and an Apollo veteran, "There just isn't the confluence of events to force the space programs



Noninvasive. Computerized axial tomographic scanners, like this one from EMI in the United Kingdom, will become important tools in medical diagnosis. These complex X-ray machines provide physicians with pictures of cross sections of a patient's anatomy.

to move forward. I just don't see space in 2000."

The major roles for space projects will lie in communications, resource location, weather modification and surveillance, and the like, according to Arthur D. Little's Martin Ernst. The economics of future ventures is still far from settled, he adds.

The power satellite is one of the concepts that should be explored, say some industry observers. Ernst believes there will be some solar-power stations in orbit by 2000—primarily experimental or prototype units sent up to develop performance and cost information.

"There are two times when you ought to run risks," Ernst states. "One is when you can afford to and the other is when you can't afford not to. Some space efforts are beginning to fall into the latter category."

Everyone agrees, however, that communications satellites have a future. Executives of Hughes Aircraft's Space and Communications Group, for example, believe the era of the space shuttle will make an enormous difference in satellites.

Because of the change in launching made possible by this program, tomorrow's satellites will be larger and heavier than present ones, says Albert D. Wheelon, vice president and group executive of the El Segundo, Calif., group. "In a way, this change is like the constraint imposed by the Panama Canal on the size of ships," he remarks. "Satellites had to fit within the shroud diameters and lengths of rocket boosters. In just a few years, those limitations on satellites will be greatly relaxed."

With their greater size, these satellites will be capable of carrying even larger solar-cell arrays and therefore will be able to produce more power for transmission. In addition, extremely large and sophisticated antenna systems will become possible, as Wheelon envisions the scenario. The result will be much greater communications capacity.

Of course, cautions Harold A. Rosen, a vice president of the Hughes group, satellites may increase in size by two or three times, but not by the hundreds predicted by some. It is just too expensive to build these city-sized platforms in space, he says.

"The argument for really gigantic satellites is that you can reuse a frequency not 4 or 10 times, but 100. I think only time will tell if these hopes pan out. From my point of view, the technology of communications satellites has progressed faster than we thought it would—and faster than the institutions that deal with them."

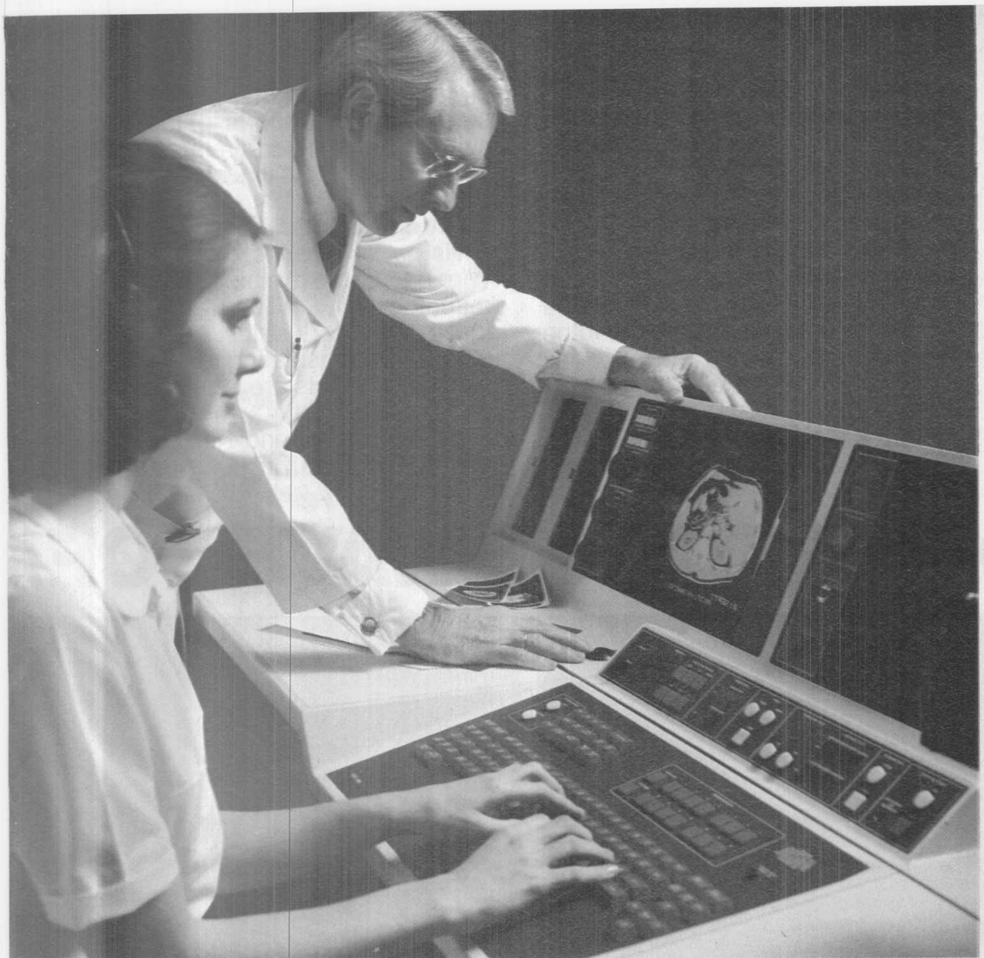
Paul S. Visher, another Hughes vice president and assistant group executive, agrees: "Our experience is that the technology of communications satellites has run something on the order of five years or more ahead of the pace at which market organizations can absorb it usefully." An example he cites is the linking of satellites and cable television. Many expected this connection back in 1965, when it was already feasible, but only now is the idea beginning to take hold.

Nevertheless, new telecommunications concepts involving greater use of satellites may change the economics. One of these emerging changes concerns the theory of economy of scale. Explains Wheelon: "Certainly it is generally more economical to provide an additional unit of service in an existing network than it is to establish a new kind of service. Yet it seems that one can operate more cheaply with a new module than with an increment to an existing system in this field. The leverage of specialization is competing favorably against the economics of scale in the satellite era. It's a simple thing to specialize the configuration of a service provided by communications satellites. It's natural to deploy them as modules in space. These technical facts are changing our economic theorems.

"I believe a new concept of telecommunications will emerge from this decade that will provide direction for the next century of telecommunications—a century that will be dominated by the communication satellite."

The anticipated explosion in the satellite population over the next two decades will undoubtedly tax the frequency spectrum, but Roy Gibson, head of the European Space Agency in Paris, does not see an insurmountable problem in that. Added channels will come from moving up in frequency, he says, noting that ESA already plans transmission experiments in the 20-to-40-gigahertz range and certainly will be exploiting much higher frequencies by the end of the century.

Electronics will expand in health care and education over the next 20 years, though in a continued context of resistance and constraint. Widespread use of



Diagnosis. Besides CAT scanners, shown at left, doctors will make increased use of digital nuclear scanners as well as fluoroscopic and ultrasonic scanners. The objective is noninvasive diagnosis that will drastically reduce the number of operations performed. Computers will provide a detailed analysis of the scan pictures in order to pinpoint exactly which are trouble spots.

computers will affect patient care, but these changes will not necessarily be welcomed by a basically conservative medical establishment. And education will still be marked by a lack of understanding of how to use electronics and a chronic lack of money, perhaps exacerbated by further taxpayers' revolts.

Therefore, any view of the future of electronics—specifically computers—in health and education must perforce be blurred at this point. If the home and workplace trends already discussed have any carryover, though, acceptance of electronics in health and education will accelerate. A populace conditioned to computers in the home may demand them in other areas, spurring the timid health and education establishments into joining the 21st Century.

One of the most exciting prospects in medicine is noninvasive diagnosis by means of computerized scanning. Indeed, these techniques could well change the way hospitals are organized and medicine is practiced, according to experts at the University of California's School of Medicine at San Francisco.

The scanning procedures—reflecting advances in computerized nuclear, ultrasonic, fluoroscopic, and X-ray equipment—will cut down the need for exploratory operations, says the UCSF team. Partly because of their cost and complexity, these machines likely will be multipurpose and used around the clock. The current controversy over computerized-axial-tomography (CAT) scanners thus may be magnified, with health insurers and the Government claiming overuse.

But more and more people will be examined on an outpatient basis, freeing more hospital beds for those actually in need of surgery. Surgical teams, armed with computer-generated diagnostic information, will know precisely where and how to operate, thus increasing the efficiency of the operating room.

Medical costs should decline as a result, and the drop in hospital admissions may permit reductions in staff—moves bound to be opposed by such powerful groups as the American Hospital Association, as well as physicians' and nurses' societies.

"Cardiac diagnostic tests will be totally noninvasive," declares Dr. William W. Parmley, cardiology chairman at UCSF. "The era of the catheter and its attendant hazards will be over."

With computerized fluoroscopy, for example, hospitals will be able to perform risk-free coronary angiograms on outpatients, predicts Dr. Alexander Margolis, the school's radiology chairman. And computers will bring to the imaging technologies the promise of enhanced dynamic monitoring and color-coded displays. Here is how these specialists see future developments:

■ Computerized axial tomographic scanners. These complex X-ray machines, which gained their developers a Nobel Prize last year, provide images of "slices" of a patient's anatomy and may come close to producing serial pictures of beating hearts, according to Dr. Parmley. The X-ray sources and sensors in current designs have rotation times of from 1.2 to 4.8 seconds, but CAT scanners in development will have 50-millisecond time intervals, Dr. Margolis says. Gated electronic scanning techniques will yield a series of pictures during each cardiac cycle.

The radiologist predicts the development of a special

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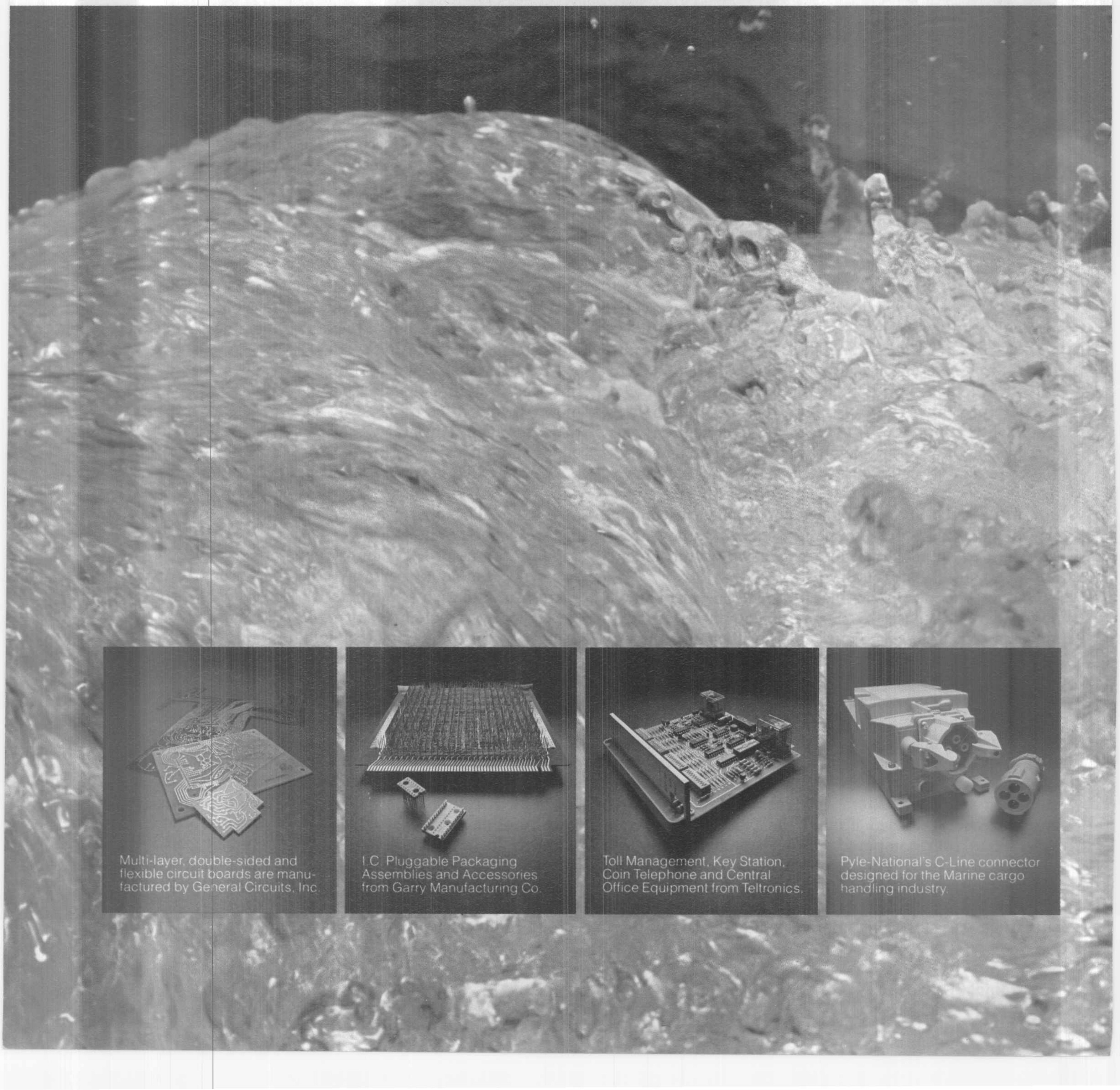
Garry Manufacturing Company,

SOME RIDE THE WAVES OF



Multi-layer, double-sided and flexible circuit boards are manufactured by General Circuits, Inc.

I.C. Pluggable Packaging Assemblies and Accessories from Garry Manufacturing Co.

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Pyle-National's C-Line connector designed for the Marine cargo handling industry.

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Pyle National Company, Chicago, Illinois. Specializes in commercial and military connectors for aircraft, missile, industrial, railroad and general purpose applications. Has subsidiaries in Mississauga, Ontario, Canada, and Nottingham, England.
Telecommunications Cable Division, Willimantic, Connecticut. Producers of a broad line of telephone wire and cable products, including fiber optic cables, at plants located in Asheville, North Carolina, and Siloam Springs, Arkansas.
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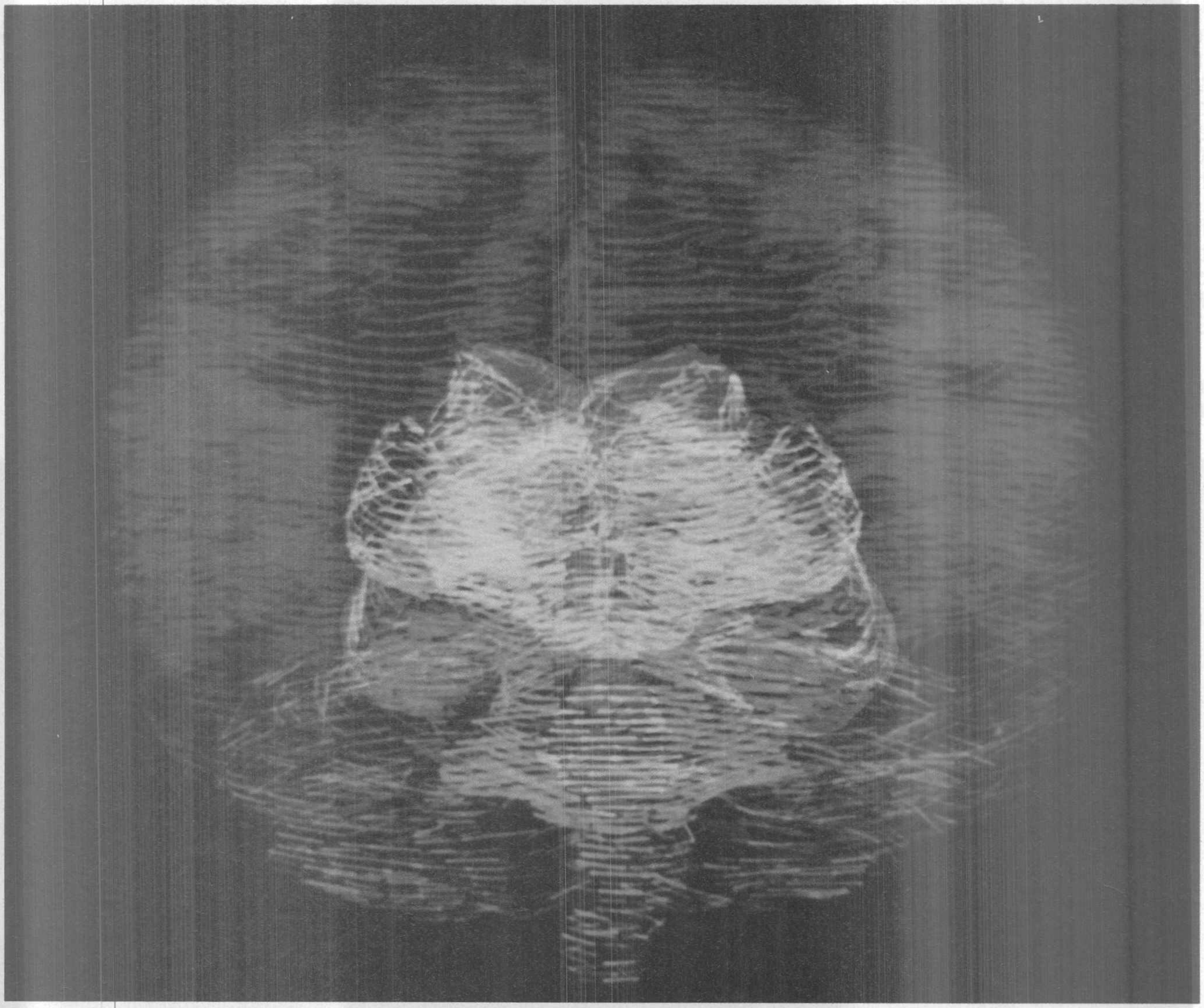

Brainy. Another means of extending teaching and research on the human anatomy will be computer-aided graphics like this color rendition of the brain done by Evans & Sutherland. The computer will also become a vital aid in diagnosing ailments outside the hospital.

anode that will drive the X-ray beams much as a TV tube is scanned. Another advance he sees will be the combination of monochromatic beams and new isotope sources for better analyses of living tissue.

■ Nuclear scanners. Now 80% analog, "nuclear imaging systems in 10 years will be 100% digital," states Dr. Robert Hattner, UCSF associate professor of radiology and nuclear medicine. Another emerging technology hailed by some and derided by others is nuclear magnetic resonance, in which signals from atomic nuclei exposed to a powerful magnetic field are used to develop pictures of the chemical makeup of tissues.

■ Fluoroscopic and ultrasonic scanners. These noninvasive imagers also will benefit from increased use of digital techniques. And Dr. Hattner foresees the development of coded apertures to produce three-dimensional sources, array processors to speed processing times, and image reconstruction that will be able to refocus picture information closer to a specific organ. "Ultrasonic and nuclear medicine will revolutionize the way we practice cardiology," Dr. Parmley declares.

Along with these strides in diagnostics, there will be advances in the use of electronics to deal with illness. Implantable devices—pacemakers and prostheses—will perform more functions for more patients and will operate not as individual units but as part of a system, according to designers at Medtronic Inc., a Minneapolis-based manufacturer of pacemakers.

The current trend toward programmability, with post-implant changes to match changes in pulse rate, width, and intensity, will evolve into a fully automatic pacer, they say. And instead of pacing only the ventricular node of the heart, future units will be connected to atrium and ventricle and will trigger a pacing pulse only when necessary. This autopacer will have a significant logic component, dictating pulse stimulation based on a variety of inputs. The goal is to emulate the natural pacing characteristics of the heart, brain, and lungs. For example, sensors will detect oxygen levels in the blood, as well as chemicals such as adrenalin, and cause the heart to respond accordingly.

Closing the loop in this manner has important implica-

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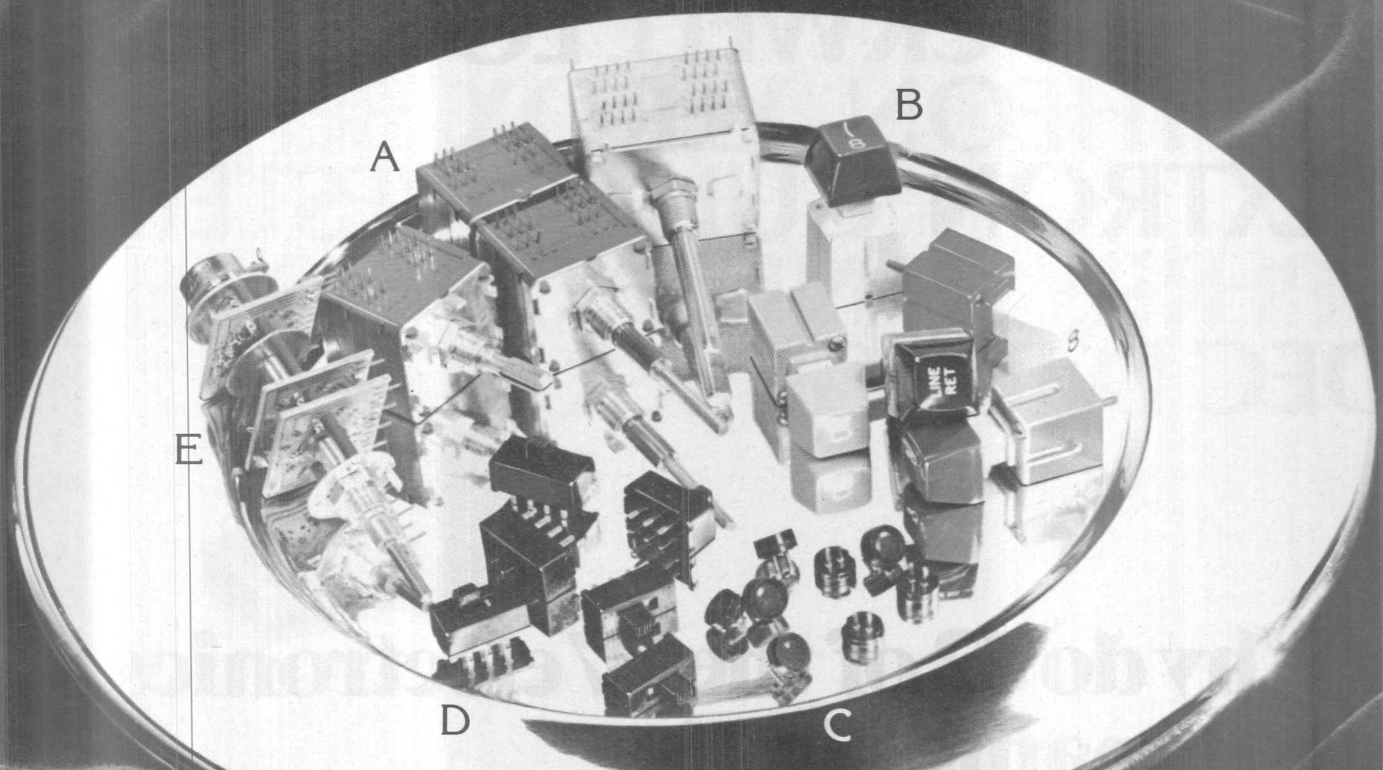

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Learning with electronics. The popularity of these Texas Instruments and other electronic teaching aids will have a growing impact on schools. Teaching will change to make use both of hand-held devices that can be used at home and in school and of large computers. In addition the use of computers to aid in teaching traditional subjects, there will also be increased instruction in programming of computers.

tions. Not only will the intelligent pacer find use in a wider variety of post-attack cardiac patients, but it might eventually help to prevent cardiac infarctions and arrest. Designers now talk about "soft," or prophylactic, applications—the insertion of pacers before the fact. Instead of waiting until patients experience an actual heart failure, they say, cardiologists might use computer analyses to pinpoint those high-risk candidates for electronic pacing.

Such screening, for example, might determine a general weakening of the heart muscle in an elderly man where the heart still responded to pumping signals but not efficiently. If a pacer were implanted to boost the triggering pulse, the heart would pump a larger quantity of blood to the brain, thereby possibly preventing a stroke or even averting senility.

Besides stimulating the heart, the pacemaker of the future will be part of a system that may also include an internal drug dispenser and an emergency device for shocking the heart going into failure.

Computerized medical records will also be a boon to patient care. Enlarged data banks will record individual histories, state- or nation-wide, including treatments and their results. Using a code, a local physician will tap into the bank and, after entering the latest symptoms by voice, will get a recommendation for treatment. The computer will also predict the probable outcome of the doctor's present therapy.

People have always been intrigued by the possibility of developing artificial organs—witness, for instance, the popularity of television's "Six Million Dollar Man." But duplicating the complex functions of human organs is not easy even with the advent of microelectronic controls. Microsurgery has made transplants of certain organs and the reattachment of severed limbs almost routine, but completely artificial organs are still a way down the road. The first steps will probably be partial replacements—devices to help malfunctioning organs perform properly.

Something that might be available fairly soon is a left-ventricular assist device with a synchronizing circuit, according to Dr. Yukuhido Nosé, director of the Cleveland Clinic's artificial organs department. "Any pump we implant will have to synchronize with the remaining natural heart," he explains. "The pumping system is now almost developed; we're just waiting for the electronics."

Dr. Nosé's department is working on an implantable artificial pancreas, but he does not think liver, lung, and kidney replacements will be installed internally.

Hans-Erich Dreyer, director of the electromedical sector at Siemens AG in Germany, predicts that artificial hearts, glands, and kidneys will be common medical items by the year 2000. He too believes the artificial kidney will be external but small enough to carry. Dreyer foresees weak or malfunctioning organs being supported by "auxiliary organs" rather than replaced entirely.

Projects in this field include a battery-driven plastic pump already being tested in animals as an implanted heart pump and an artificial gland that ultimately may dispense insulin into the bloodstream of diabetics. The electronically controlled dosage system will continually supply the insulin in minute quantities according to a preset program. However, artificial glands that are part of a closed-loop system and supply insulin only on demand will not be realized during the next two decades, the Siemens official cautions.

Computers will continue to gain a growing position in education. A recent survey of 1,800 public schools conducted for the National Institute of Education found that about 15% of all U. S. public schools are using computers for applications directly associated with students. These include testing and student administration, teaching data processing, and computer-assisted and -managed instruction. And the study found that of the school districts without computer

Unmanned spotter. The military will equip field forces with unmanned aircraft for target acquisition and reconnaissance missions. This 6-foot-long aircraft is part of an aircraft system being developed by Lockheed Missiles & Space to carry spotting equipment.

involvement, 87% are planning to have machines at some time in the future.

Obviously the need and desire exist. But some observers see a necessity to rethink how the computers will be enrolled in the classroom, and once there, how they will be used. Analysts Thomas C. Thomas and Victor Walling of SRI International's Center for the Study of Social Policy in Palo Alto expect these considerations to raise some perplexing problems for local, state, and Federal authorities.

As people begin to turn away from traditional public schools and toward home computers to fill the educational needs of their children, the analysts fear increased strains on community school systems and a widening of the proficiency gap between those who can afford the home computer and those who cannot. How does government cope with the poor and disadvantaged as education for the affluent moves out of the school and back into the home, they ask.

But on the other hand, the idea of superimposing computer systems on an otherwise unchanged school system will probably not work, either. So far, computers in the classroom have essentially been programmed for drill and practice routines, for simulations, and for teaching simple programming languages, usually Basic. All three of these applications are unimaginative and unproductive for they serve only to perpetuate inadequate traditional teaching methods. This criticism comes from Seymour A. Papert, professor of mathematics at MIT, who for many years was co-director of the Artificial Intelligence Laboratory at the institute and head of a project dealing with the use of computers in the education of children.

In subtle and not-so-subtle ways, he says, the present use of the computer programs the child rather than letting the child interact with the computer. How should this approach change?

The computer can enter the educational process in a profoundly different way, Papert writes in his contribu-

One such way has been under investigation at the MIT Children's Learning Lab. There, school children learn a computer language, LOGO, which they then use to program and interact with computer-controlled devices.

One of these devices is the "computer turtle," a cybernetic animal that a child controls by programming the computer. The pupil is in control and works with the teacher to solve a problem, such as getting the turtle to draw a square by writing instructions to the computer. "To square" can then be encoded in the computer's memory so that the child does not have to repeat the long set of instructions originally required for the turtle to trace the shape on the floor.

"For young children, the operation is conceptualized as teaching the computer a new word, and how to teach becomes not only a metaphor for how to program but a theme of the child's activities in the learning lab," Papert reports. The child learns to see formal mathematics as a symbolic language, a style of articulating different from any he yet knows: pupil and teacher work as partners to solve problems set up by the youngster.

Few countries are as sensitized to computers as France. Understanding and support of computers extends from high government circles right down into the school system.

An ambitious part of a five-year program undertaken at the end of 1978 is to put microcomputers into every one of the 7,200-odd secondary schools in France and teach masses of students how to use them. It's a big project, but the government is giving the plan its full financial backing.

A first batch of 400 microcomputers went into the lycées early in the 1979–80 school year. Half were from Logabax Informatique SA, a Paris-based minicomputer house. The other half came from the Société Occitane d'Electronique (OE) of Toulouse, a firm that got its start in video games. Both the Logabax and OE machines are standard models that have 32 kilobytes of random-access memory, twin floppy disks, a full keyboard, and a cathode-ray-tube display, and they sell for about $4,000.

A second batch of standard microcomputers will arrive in the 1980–81 school year, not necessarily from the two original suppliers. After that, the Ministry of Education may well opt for a special system.

"Experience may show that the instructor needs to have access to each student's working memory so he can check what the student has done," explains Francis Baçon, a consultant in the Mission à l'Informatique, a task force set up in the Ministry of Industry to coordinate the government's program. "Each school could wind up with from four to eight terminals tied to a central unit," he adds.

To make sure the microcomputers get used, the government's program calls for training 10,000 instructors to teach students with them. Software is already available in the form of 400 programs prepared in a pilot program at 58 lycées, and more will be added as the project progresses.

Although this mass effort will be made in the second-

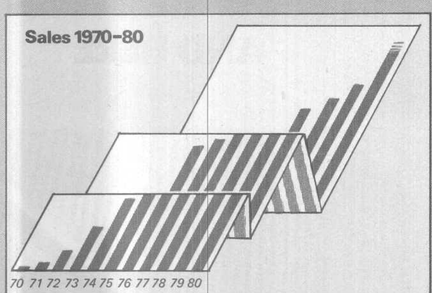
"When you've got something good to offer, you just don't sit back and wait for your time to come."

Meet Takayoshi Shiina. Age 36. President of SORD Computer Systems, Inc. A man with a purpose.

"In Japan, the conventional route is to enter a well-established company after graduation from college. Then you sit back, be nice to your superiors, and wait for seniority to bring you to a position of leadership and security. But you couldn't get me to jump on that treadmill for anything."

In April 1970, at age 26 Takayoshi Shiina established SORD. Initial capital: $2,600. Total staff: 2.

"I knew that what the public would be looking for in the coming years were general-purpose computer systems that could be operated by just about anybody, with no special training. And I knew that I had the ability to develop both the hardware and software required for such systems."



SORD's first original product was a floppy-disk system introduced in October 1973.

"As the result of years of independent research and development, today SORD offers a full lineup of superior-quality hardware and software products. Our M200 mark Series small professional computers, for example, feature large-capacity memories, outstanding data processing speed and unbelievably easy operability. In software SORD has developed a wide range of unique and highly acclaimed products. Like our brand-new Pan Information Processing System – **PIPS** for short. **PIPS** is a data-based general-purpose user's program that accomplishes simply and quickly the work which used to take a month with BASIC and up to three months with an assembler."

M223 mark VI with hard disk

In October 1980 SORD plans to introduce its newest product line: the SORD M400 Series 16bit supermicrocomputers.

"SORD has come a long way since I started the company exactly 10 years ago this month. We presently have a permanent staff of 135, and our sales continue to grow by leaps and bounds annually. The reason for our phenomenal success is simple, though. At SORD we know what the people want. And that's precisely what we strive to give them."

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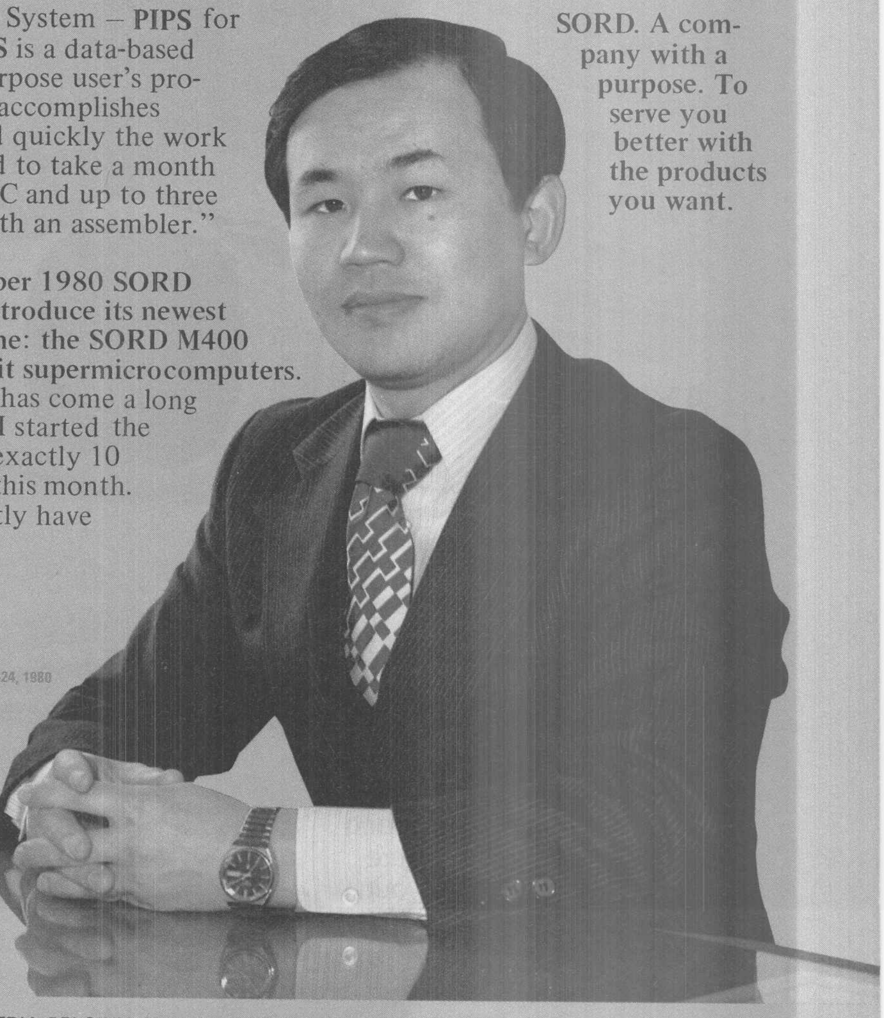

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Circle 10 on reader service card


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ary schools, the universities have a place in the government's overall plan to speed the application of computers. They have been instructed to prepare to train at least one third of their students, not counting those specializing in computer sciences, in computer applications related to their specialties. Pilot efforts toward this goal started in 1979, and the program should be in full swing by next year.

On top of all this, there will be an adult-education drive to sensitize engineers and technicians, particularly those working in small companies, to the applications of microprocessors. In the next decades, education by and about computers may well prove that over 50 million Frenchmen can't be wrong.

Electronics has held an integral place in national defense since World War II and will certainly continue to do so.

In the 1970s, however, the support of high technology by the Defense Department waned. That is why the very high-speed integrated-circuit (VHSIC) program is regarded by many as so significant, marking the DOD's return to promoting high technology. The applications of VHSIC could become crucial to the defense hardware.

"The watchword in defense studies in the past four or five years has been 'force multiplication,'" says Richard D. DeLauer, executive vice president of TRW Inc., describing what in a previous era was called "more bang for the buck." And how is this accomplished? "We have to do it with equipment."

The keys in tactical defense remain command, control, communications, and intelligence, DeLauer says. "Our present equipment doesn't do the job because we lack devices fast enough for signal processing, which is central to command, control, and communications. That's where VHSIC comes in."

With VHSIC devices designed into equipment, "we can start thinking about new schemes of battlefield management," DeLauer goes on. One example he offers of this type of signal processing is in target acquisition. "A helicopter pops up over a battlefield, takes pictures of targets, and matches them up in a computer, which then predicts their position for firing. This image intensifying will be made possible by VHSIC. We can't do it now."

Implicit in all future military systems is digital communications. In fact, DeLauer considers it a must. The new 1192-93 network for the DOD is a start, he says, the next step being NATO compatibility. Voice communications as well as video transmissions will be secure.

Equipment for undersea surveillance will become as sophisticated as airborne detection hardware, predicts Robert Pry, vice president for technology at Gould Inc.

Increased understanding of undersea signal processing will make possible new types of sonar equipment. Inexpensive optical hydrophones will directly transform sound into light, at low energy levels, for transmission to surface or land-based centers, Pry says, while sonobuoys and bottom-sound detection devices will abound.

In the air, he expects that "fly by fiber optics" will be as common as "fly by wire" is now. Actually, he sees a combination of fiber and copper wire for aircraft—wired local actuator-accumulators with command links using optical fibers.

Remotely piloted vehicles (RPVs) for airborne surveillance will continue to be developed. Moreover, Pry anticipates remotely piloted submarines (RPSs) using guidance technology developed for the cruise missile to follow undersea terrain. Like the cruise missile, the undersea version will be a seek-and-destroy weapon.

As for radar—like Kansas City, it seems to have gone as far as it can go. Observers feel that air-defense radars at the end of the century will have substantially no more reach than they do now. For example, the latest long-range radar built by Thomson-CSF in France can spot aircraft as far off as 280 miles. According to Michel Carpentier, general technical director for the company, the successors to the TRS 2230 will not have much increased range but will have markedly superior resolution, antijamming capability, and reliability.

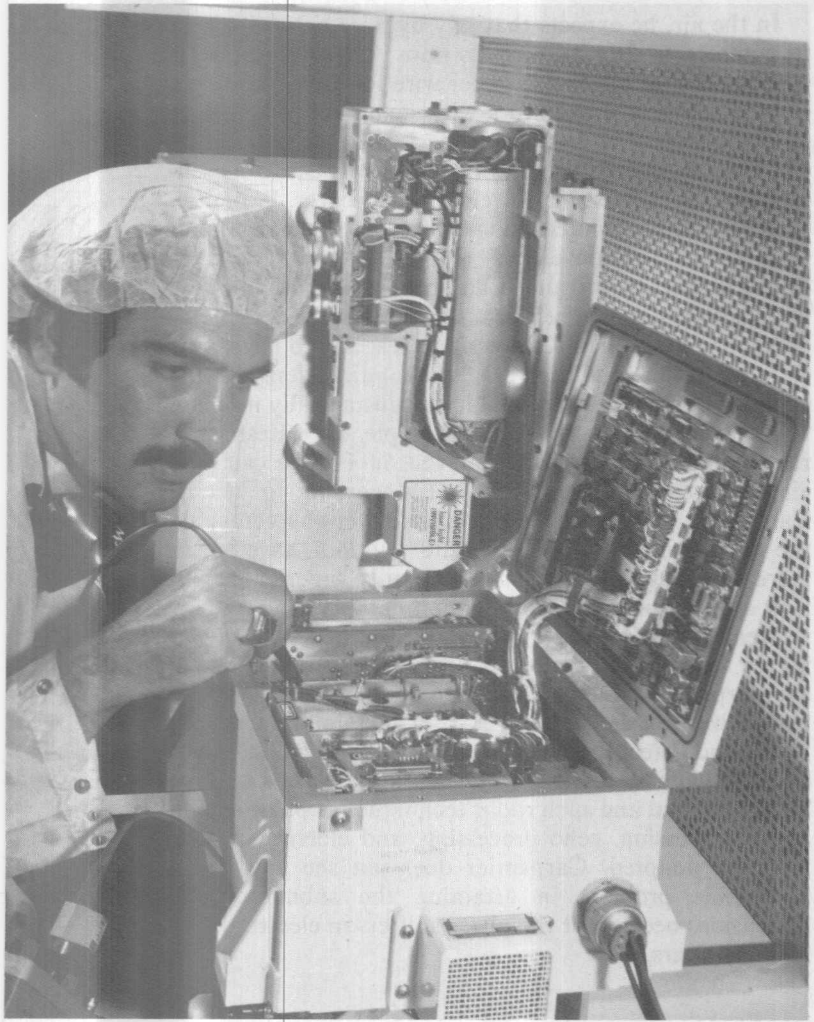
Meanwhile, Carpentier forecasts spectacular advances in the lidar (light detection and ranging), the optical counterpart of radar. "Lidars today are about where radars were in 1934," he says. "They simply send out pulses and detect the return echoes." There will be major developments by the end of the century as lasers become more powerful and such radar techniques as pulse coding and compression, echo processing, and electronic scanning are adapted. Carpentier does not see any insurmountable problem in attaining the submicrometer dimensions needed for the phase shifters in electronically scanned lidars.

Aside from communications, detection, and command devices, what about guns? The sci-fi set has had plenty of exposure to laser guns, but researchers in the real world have some doubts about developing a portable laser weapon capable of knocking out an enemy plane or ground vehicle. "Is it an efficient weapon, given the amount of energy necessary to generate a potent beam?" one defense contractor asks. "Could you imagine a soldier carrying around an arc welder?" The particle-beam gun, another sci-fi favorite, also does not seem likely in the next 20 years.

More likely will be improvement in the guidance systems of present-day missiles. For example, the Maverick missile initially was homed in by television but is now equipped with forward-looking infrared guidance. In other words, the weapons systems of the 1990s and beyond could look much like today's but have a far greater degree of accuracy, target discrimination, and ease of maintenance.

The enhanced performance of conventional weapons might permit a defense strategy that would not have to depend on nuclear weapons. "By the year 2000 we'll see a leakproof missile-defense system," predicts George Heilmeier, vice president for corporate research, development, and engineering at Texas Instruments and a veteran of ballistic-missile programs.

Nuclear weapons became a keystone of 1950s strategy



Laser gun. Although there is little chance that infantry troops will be armed with laser guns in the near future, lasers will be used in other weapons. Here an engineer tests a laser rangefinder on the Army's Division Air Defense gun at Hughes Aircraft Co.

because aerial bombing was not very accurate. However, extremely precise weapons capable of finding specific targets with zero error probability are definitely in the cards.

As for a "leakproof" missile-defense system, Heilmeier notes that today's tactics are based on intercepting incoming ballistic missiles as they reenter the atmosphere. But a much better time to attack them would be just after they are launched. This objective suggests the need for advanced surveillance systems and a strike mechanism with multishot capability that can be accurate over long distances, Heilmeier points out. Therefore lasers, though not carried by individual soldiers, may very well have a mission after all—mounted on space platforms and standing guard on the horizons.

The computers that are incorporated into weapons systems are usually specially designed. Even the general-purpose processors are more than likely altered to meet environmental specifications. Some military computers are so special that they cannot be separated from their weapon system. Because of these specifications, their software is also individualized—created from scratch for each system.

The problems posed by these diverse and special units are important "because they account for a major part of the frustration . . . with which most of the defense community now reacts to computers and software," writes J. C. R. Licklider, former director of the DOD's Advanced Research Projects Agency and now professor of computer science at MIT, in his essay in "The Computer Age: A Twenty-Year View."

The solution could begin with the design of computers applicable to varied weapons systems. Greater engineering discipline in the development of software would be a part of this effort, too, as well as research into the use of high-level languages and advanced software development methods in weapon systems.

However, the Pentagon faces a dilemma in trying to standardize programming languages and methods. On the one hand, it might want to decide on a standard software development system before there are too many different systems. On the other hand, it might decide to defer standardization until the choices are clear.

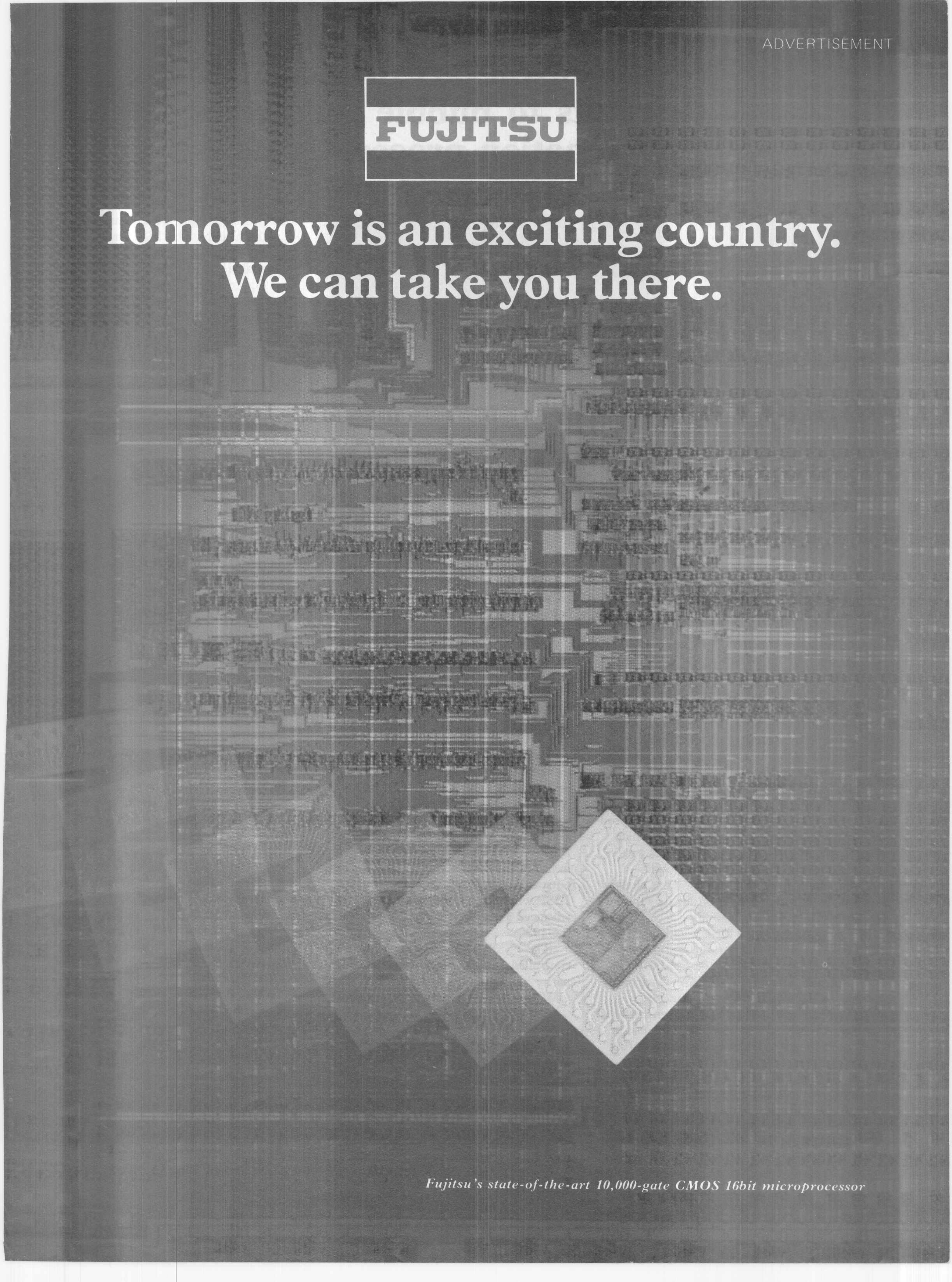
One solution suggested by Licklider is to have a network-based software center to oversee widely distributed development resources and provide protocols for their use.

Another difficulty cited by Licklider is the fact that military systems, unlike civilian versions, cannot be readily tested under working conditions—in their case, the battlefield. During an actual trial under fire, the results are often too confused to provide a judgment of their effectiveness. However, the computer offers an opportunity, through simulation, to test defense systems—making it possible to exercise the fleet while it is in the harbor, so to speak.

These are just a few of the challenges that will mold the future of computers in national defense. Another problem to be solved concerns controlled information sharing and the equally vital need for computer and network security. Defense systems, like their civilian counterparts, will also be affected by developments in the speech-recognition and self-diagnosis fields.

Still another challenge here is to devise a system giving a commander both rapid access to all raw data at his echelon and below and at the same time the capacity to pass along only his interpretation of that mass of information to his superiors in the chain of command. Besides computer and network security in the command chain, the military will require protection of its communications from such countermeasures as jamming and disruptions of traffic flow. Packet-switching networks are seen as promising in this regard.

Implicit in the outlook for defense electronics, particularly for the development of computer systems, are indications that the Pentagon once again will take the initiative in funding advanced technology. As Licklider suggests, this involvement will be critical not only for national security, but for the advancement of information-teleprocessing technology. □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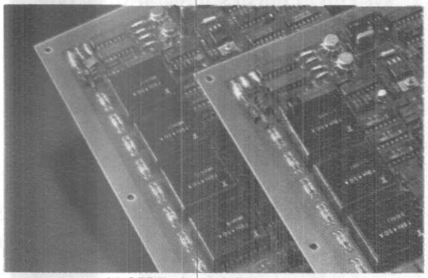
Circle 217

1Mbit Bubble Memory in Preparation

As a fundamental phase of its ongoing development of bubble memories, in 1980 Fujitsu is preparing sample shipment and mass-production procedures for its newly developed 1Mbit bubble memory device. To meet the latest market needs, the new 1Mbit bubble memory device is designed to serve as a program memory, mini-file memory and as a file memory for terminals and other equipment.

Fujitsu entered into bubble memory development in 1970. It currently markets 64Kbit and 256Kbit bubble memory devices which are widely acclaimed for their high reliability, non-volatility and suitability as non-mechanical fixed file memories. In June 1980 Fujitsu will complete its all-LSI support circuitry, thereby permitting bubble memory cards offering enhanced miniaturization and reliability.



128KB bubble memory cards

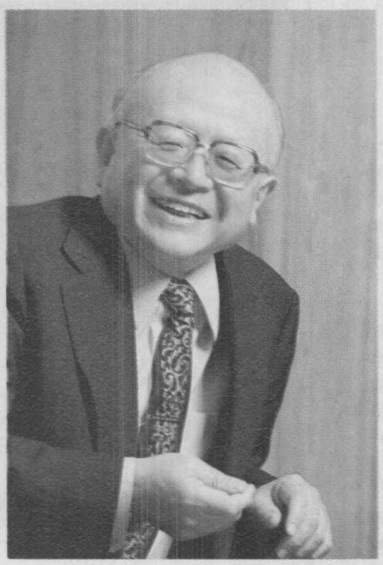
Among its unique bubble memory products, Fujitsu was the first company to develop and market a bubble cassette to replace paper tape and card readers as program loaders in testing equipment. This bubble cassette is currently offered in 64Kbit and 256Kbit models.

Following sample shipment and mass-production development of its 1Mbit bubble memory coming soon, Fujitsu is preparing to move next toward the development of a 4Mbit memory.

Circle 218

INTERVIEW: Dr. Bun-ichi Oguchi

Executive Director, Fujitsu Ltd.
Executive Vice President, Fujitsu Laboratories Ltd.



Dr. Bun-ichi Oguchi

Q ***As Japan's largest computer manufacturer, how does Fujitsu see the present computer situation as we embark on the new decade of the '80s?***

During the 1970s, Fujitsu's main concerns were the development of very large-scale computers and of small-scale general-purpose computers offering enhanced performance features. Two factors contributed significantly to such development: the striking progress seen in LSIs, and in software in general. As a result of the trend toward ever more general-purpose systems, computers have emerged from their earlier specialty status to become items which can be operated easily by more and more people. The progress seen in LSIs has been particularly outstanding, with memory capacities advancing at the rapid rate of 400% every two years. Today, in 1980, we are on the threshold of the age of the 64Kbit DRAM. In ultra high-speed logics, logics featuring 100 to 1,000 gates per chip are already in use in large-scale computers. And small-scale systems utilizing 10,000-gate-per-chip CMOS LSIs as the CPU are receiving the benefit of today's sophisticated LSI technology even more directly.

Q ***What direction do you see for future computer LSIs?***

As I just mentioned, today we have reached the stage where 64Kbit DRAMs are used in practical applications, and logics offering ultra high rates of speed and high integration are also currently coming into use. Since VLSIs represent the amalgamation of various sophisticated technologies, a great deal of work is required; however, the results of our research will surely be showing up on production lines before long. As a followup to our 64Kbit DRAMs, for example, memories offering four times that capacity will be available in the not too distant future.
Today Japan's LSI mass-production technology is said to be the most advanced in the world. In the future, however, as LSIs come to be used not only in computers but also in a wide range of other products, the emphasis is forecast to change from mass-production of a few varieties of LSIs to limited-quantity production of a wider variety of LSIs. To meet this future shift and yet continue to produce LSIs at moderate cost, at Fujitsu we are currently offering our series of Master Slice Family semi-custom LSIs based on CAD and other technologies.

Q ***What do you see happening in the coming years in terms of bubble memories and other peripheral memory devices?***

Fujitsu presently offers 64Kbit and 256Kbit bubble memory devices, as well as 32KB and 128KB bubble memory cards. We have also begun marketing our unique bubble memory cassettes. Looking ahead, by the end of this year we plan to introduce our 1Mbit bubble memory device onto the market.
In disks, we are currently developing models offering several times greater density than disks now available: in other words, disks of 20,000bpi and higher. We are also investigating potential uses for optical disks and proceeding with their development.

(Continued)

devices to GaAs FETs—are the inside on the expanding world of telecommuni

Outstanding Lineup of Optical Semiconductor Devices

Based on long years of experience in the development of optical communications technologies, Fujitsu currently offers a wide range of high-performance optical semiconductor devices with proven reliability for a broad spectrum of customer needs.

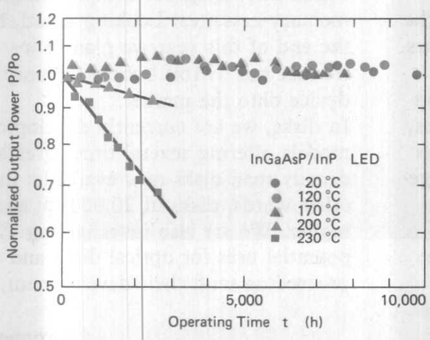
In the 0.8μm wavelength region, Fujitsu's light source selection includes AlGaAs LDs (laser diodes) and AlGaAs LEDs (light emitting diodes), while in detectors Si APDs (avalanche photodiodes) and Si PIN photodiodes are now commercially available.

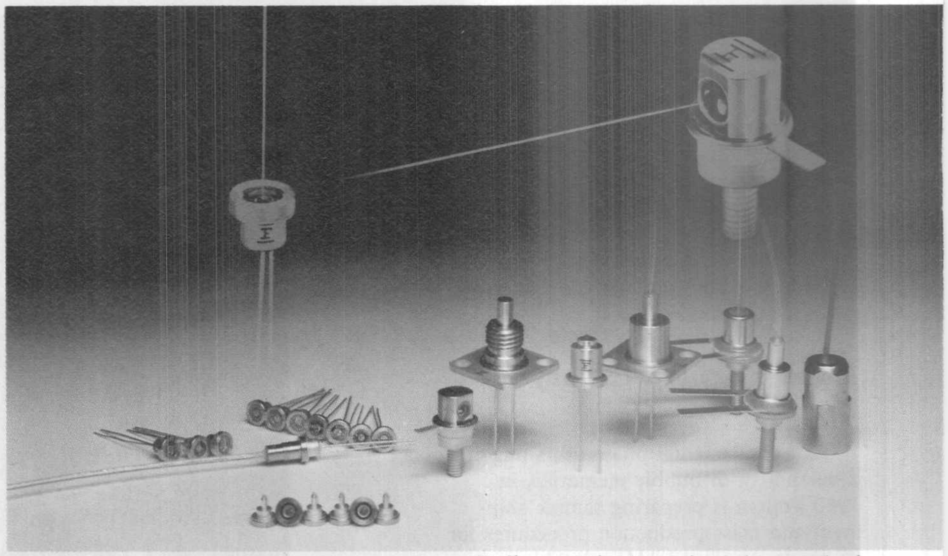
Fujitsu's AlGaAs double heterostructure LDs are specially designed as highly reliable light sources for optical communications in the 0.8μm wavelength region. They feature a high 15mW output, stable cw operation over a wide temperature range from -40 to $+70°C$, a long 10^5-hour operating life at an output of 5mW at room temperature, and monitoring optical output for automatic power control. They can also be used in a wide variety of applications such as laser printers, POS terminals and video disks.

Fujitsu's 0.8μm LEDs with a cut-off frequency of 30MHz have an output capability of more than 200μW coupled into a 0.17 N.A. 85μmø step index fiber at 100mA. The LEDs with a cut-off frequency of 100MHz are also available on request. Their operating life at room temperature is estimated to be over 4×10^7 hours.

In optical detectors, Fujitsu's Si APDs are hermetically sealed with a sapphire window for excellent performance and high reliability. An outstandingly high quantum efficiency of 80% has been achieved, with an excess noise factor as low as F=4 at a multiplication of M=100.

Result of accelerated aging of InGaAsP/InP LED at elevated temperatures





Fujitsu optical semiconductor devices

In addition to its excellent selection of 0.8μm region products, Fujitsu is also engaged in the development of a full variety of optical devices for the 1μm wavelength region. InGaAsP LEDs and Ge APDs are already commercially available, and an InGaAsP LD and InGaAs photodiode are presently under development for application in the near future.

Fujitsu's 1μm InGaAsP LEDs are capable of over 50μW output at 100mA when coupled into an 85μmø step index fiber. Their cut-off frequency is typically 30MHz. Operated at room temperature, these LEDs offer an expected half-life of up to 10^9 hours. And being fiber-coupled, they are extremely easy to use.

For the 1μm wavelength region, Fujitsu's Ge APDs feature a quantum efficiency exceeding 60% and an excess noise factor of F=10 at M=10. Their cut-off frequency is 600MHz, with a light detecting capability through the 1.6μm wavelength region.

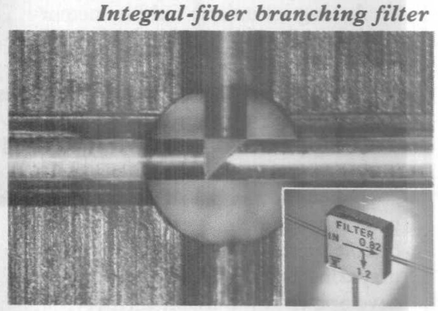
Circle 372

World's First Integral-Fiber Branching Filters

Integrating its standard optical semiconductor technologies with advanced technologies in the areas of coupling, connectors and peripheral circuitry, Fujitsu has developed a full lineup of optical fiber link modules. These modules are incorporated in Fujitsu's series of optical fiber link systems, which include 1.5Mb/s–32Mb/s digital models and 6MHz–30MHz analog models. Because of their ease of installation and outstanding cost performance characteristics, these systems are ideal for use as simple transmission links in computer-computer and computer-peripheral data transmission as well as in TV transmission.

Fujitsu has also completed development of a wide range of high-reliability connectors, couplers, branching filters, switches, attenuators and other passive components designed to support its optical transmission systems, such as its ultra high-speed PCM transmission systems. Fujitsu's integral-fiber type couplers and branching filters based on advanced Fujitsu fiber processing technology have won especial acclaim for their compact size, high reliability and low loss characteristics far superior to those of conventional discrete circuitry type optical components. Fujitsu is in fact the world's only manufacturer to offer integral-fiber branching filters, providing sound proof of Fujitsu's outstanding technological achievements in this area.

Integral-fiber branching filter



Circle 373

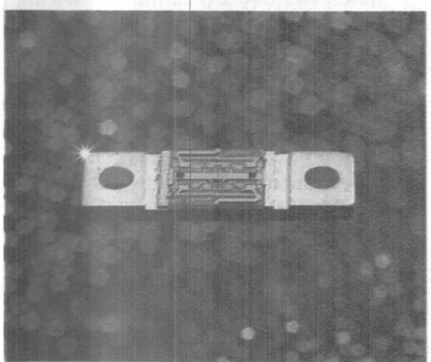
from optical story cations.

INTERVIEW: Dr. Bun-ichi Oguchi

GaAs FETs Enter IC Age

Since developing the world's first power GaAs FET in 1973, Fujitsu has consistently been a forerunner in this field. Fujitsu developed the world's first normally-off GaAs IC in 1977, and now it is undertaking development of GaAs ICs designed for wide use in the 1980s.

Fujitsu currently offers a broad range of GaAs FETs, from 2 to 20GHz, including power GaAs FETs in the 4 to 12 GHz range. The 8GHz power FET, for example, features a power output exceeding 10W. Fujitsu power GaAs FETs provide a power-added efficiency of greater than 40%, the highest in the world.



GaAs linear IC

Fujitsu's new devices currently under development are its GaAs linear IC and GaAs digital IC. When completed early in 1981, the GaAs linear IC will be able to serve as a microwave subsystem only 4 x 4mm in size. This will represent a 1,000 times reduction in volume compared with conventional subsystems incorporating discrete GaAs FETs. The new GaAs linear IC will have the additional advantage that it will be applicable to a variety of frequency ranges (2–4 GHz, 4–12GHz, 12–18GHz), thereby achieving subsystem standardization.

Fujitsu's new GaAs digital IC, on the other hand, is being developed as a logic IC for super high-speed digital telecommunications systems and high-speed, large-capacity computer systems. Employing the normally-off operation mode, Fujitsu's GaAs digital IC is to feature 6 to 10 times the speed capability of conventional silicon-based ICs, while further attaining reduced power dissipation. A high performance of 70psec/gate at 100 fJ has already been achieved. Future plans call for development of a GaAs digital IC offering the high speed of the Josephson junction at room temperature.

Circle 374

Q ***What do you see happening in the area of telecommunications during the 1980s?***

The 1980s are generally envisioned as the decade where we will come to see a widespread increase in the use of digital networks and optical communications technologies, combined with the development of new services which these technologies make possible.
In Japan, the everyday telephone may be said to have already permeated throughout all facets of life. The target now is to succeed in converting existing telephone networks to digital ones, in order to introduce a variety of new services. Moreover, this must be accomplished at moderate cost. As the result of recent achievements in semiconductor technology—the introduction of electronic switching systems and solid-state transmission equipment, the advent of LSI coder-decoders, etc.—economical digital telephone communications networks are today approaching a level of practical feasibility. Not only will digital voice transmission thus soon be realized, but great strides will also be made toward practical implementation of transmission of data and video—including facsimile signals—using the same transmission networks used for voice transmission.
In the area of optical communications, owing to the characteristics of lasers, digital systems are judged more suitable than analog systems. With high-speed digital transmission, e.g. video transmission, optical communications technology is viewed as outstandingly practicable, accelerating the development of this technology in the future.

Q ***Would you agree that Japan leads the world today in the field of optical communications technology? How do you evaluate Fujitsu's role in this area?***

Japan has been right at the top in transmission technology for some ten years already. Naturally our optical communications technology has been at that superior level right from the beginning. As one of the world's leading comprehensive manufacturers of telecommunications equipment, Fujitsu was a forerunner in optical communications R&D, and today Fujitsu offers a full variety of state-of-the-art optical systems which are highly competitive on the world market.

Q ***When do you foresee optical communications technology being used in the telephone network, and what problems remain to be solved before this can be accomplished?***

I think we can expect to see optical communications applied to the telephone network for short-haul transmission in the very near future. As for the problems remaining, at Fujitsu we are currently engaged in the development of laser diodes, optical detectors and other components with improved characteristics and longer service lives as required to achieve lower-loss optical transmission. We have already developed such components with 0.8μm wavelength capability, and we are now working toward components for wavelengths exceeding 1μm.
Looking farther into the future, one day optical transmission lines will be used not merely over long distances but will also reach subscriber sites for widespread use in video transmission, such as for two-way TV.
I think the general public can realistically plan on having such services in the future.

(Continued)

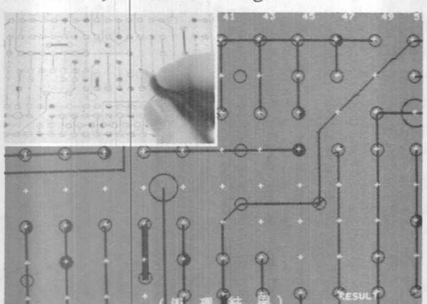
FUJITSU

Product reliability and modern produc are today's guarantees, R&D will secure tomorrow's promise.

New Achievements in Pattern Recognition

Fujitsu has successfully developed a new technique to boost its already impressive lineup of pattern recognition technologies. The latest development is a printed circuit wiring design reading system. Using a grid transformation method, the new technique vastly simplifies printed circuit wiring data input for computer-aided design, accomplishing in but 10 minutes the work formerly requiring several hours.

The new printed circuit wiring design reading system is but the latest development in Fujitsu's continuing program of pattern recognition techniques. Such techniques are beneficial in simplifying computer input of such data as characters, voice and images.



PC wiring design (above) computer-processed using grid transformation method (below)

In the area of character recognition, Fujitsu's OCR mechanical printed-character recognition technique currently permits high-speed reading of more than 2,000 different Chinese characters. Handwritten Chinese characters, *kana* syllabary characters and alphanumerics can also be read.

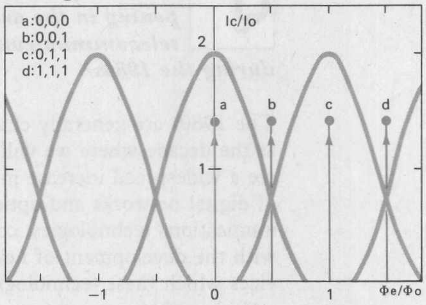
Fujitsu speech recognition technology presently allows accurate reading of approximately 100 types of spoken words. And in the area of graphic pattern recognition Fujitsu has developed a unique map reading technique using image approximation by polygonal lines. This system is already being applied in actual service.

Circle 375

9-Gate 4bit Parallel Full Adder Circuit Developed

The field of Josephson junctions is widely recognized for its overwhelming potential impact on computer systems of the future. Fujitsu has recently achieved yet another milestone in this vital area with the development of the world's first

Sum generator



Movements of the operating points for the sum generator on the threshold characteristics of DC-SQUID type Josephson junctions. Abscissa is indicated by the external flux caused by the input signal currents. Situations a, b, c and d correspond to the logical situations when the number of "1"s is 0, 1, 2 and 3, respectively.

4bit parallel full adder circuit which uses as few as 9 gates.

Whereas conventional Josephson junction circuits have required 7 gates per bit, Fujitsu's new circuit has reduced this number to 2 gates per bit. This technological development was made possible through utilization of the DC-SQUID type Josephson junction characteristic that the threshold curve periodically changes in response to input signal currents. As a result, Fujitsu's new 4bit parallel full adder Josephson junction circuit requires a total of only 9 gates, an unprecedented achievement.

Fujitsu is currently engaged in the development of new type gates and circuits, aiming toward the realization of Josephson computers.

Circle 376

State-of-the-Art Multilayer Printed Wiring Boards, Microconnectors

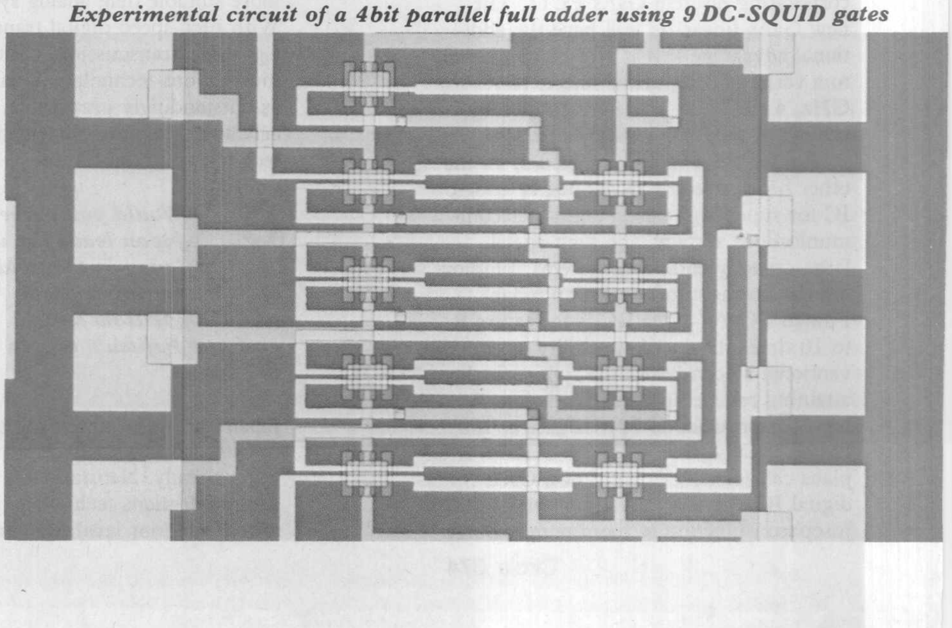
Today's high-performance all-LSI computer demands constant improvements in circuit speed and packaging density to enhance its speed and reliability. To meet these requirements, Fujitsu provides multilayer printed wiring boards and microconnectors of superior quality which represent the highest density available today.

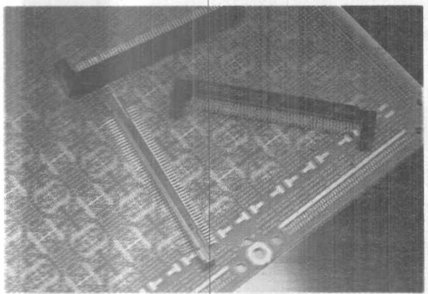
In a small 190 x 190mm space, the Fujitsu high-density multilayer printed wiring board contains no less than 400X and 400Y channels, 10,000 through-holes, and 800 I/O terminals. Wiring patterns are only 150μm in width. The aspect ratio, i.e. board thickness vs drill size, is almost 6.

To produce its superior printed wiring boards, Fujitsu has developed a variety of unique production techniques. Its precision technology generates patterns as small as 150μm. Its drilling technique makes possible through-holes as small as 400μm in diameter. Other superior technologies ensure size uniformity combined with a high resistance to heat and flammability. Uniform plating and precise positioning of layers are also Fujitsu's landmark technologies.

The microconnectors used on Fujitsu's multilayer printed wiring boards feature the highest density in the world, with a pin spacing of 1.27mm and 100 pins per connector. To produce the extremely fine male solder leads, Fujitsu has developed a number of superlative production technologies. These include a

Experimental circuit of a 4bit parallel full adder using 9 DC-SQUID gates

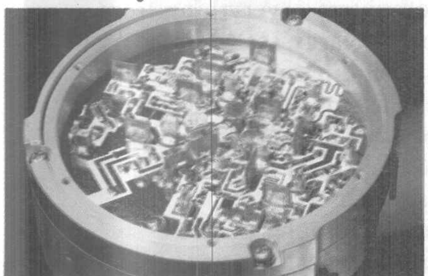




low-pressure molding technique and new materials for its use. Fujitsu has also developed a new design system which has substantially improved the reliability of its female contacts. All products are subjected to extremely rigid microscopic inspection to ensure their high quality and precision.

Circle 378

Submarine Repeater Components Offer Top Reliability



Submarine repeater amplifier

Submarine coaxial cable systems today serve as vital communications links in nearly every corner of the globe. Due to their difficult accessibility, however, such submarine communications systems demand component parts meeting extreme standards of reliability, standards exceeding those for most other components.

Through a stringent series of quality control and reliability tests, Fujitsu has made impressive strides in producing the submarine components in demand. Its submarine repeaters, for example, comprise components manufactured under the most rigorous guidelines to ensure superior quality control and reliability. The failure rate of a Fujitsu submarine repeater is as low as approximately 25 Fits (1Fit=one failure per billion hours). And Fujitsu's submarine repeater transistors—the components most crucial to the smooth operation of the entire submarine system—feature a high reliability rate of 1Fit, the result of rigid manufacturing controls, product screening and long-term aging tests.

Circle 377

Q ***What is Fujitsu's basic policy regarding R&D?***

Fujitsu has achieved and currently maintains a very high level of technological capability in a wide variety of areas. What will be in demand in the 1980s is R&D leading to technologies with more direct practical applications and benefits for the general public. In this respect, it is quite important to bring technological developments to a more generalized level and to create new systems which are designed for use in non-specialized applications. This does not mean, of course, the replacement of sophisticated technologies with those more simplistic, but, instead, the achievement of economical and highly reliable systems on the one hand incorporating the highest technology while at the same time offering complete ease of operation to the non-specialist. For example, in office automation, developing computers permitting input and output of information in the form of voice and images will be a focal point, demanding all-out efforts in the area of pattern recognition technology.

Q ***What do you foresee occurring in the area of office automation?***

At Fujitsu our main goal is to improve data, words and document processing and information retrieval capabilities using office computers and various I/O and terminal equipment, as well as to improve data, voice and image transmission centering around EPBX's, facsimiles and other telephone-related terminals. In developing new office equipment, we place major importance on such points as meeting office needs, offering ease of operation, compact size, economy, etc. To achieve these, we look toward improved pattern recognition and other man-machine interface technologies, more sophisticated LSIs and other devices, and the development of easier-to-use program languages. We also feel it is particularly important for us to work toward the development of ever more effective Japanese language processing capability. In short, we would like to create a superior system integrating all of these many advantages.

Q ***What is Fujitsu's High Reliability Program, and what has it accomplished?***

Fujitsu's High Reliability Program began in 1966. It extends over the full range of Fujitsu activities: R&D, technology, design, manufacturing, installation, maintenance, etc. Its aims go far beyond merely trying to eliminate product defects and production errors. Instead, the program serves to educate each and every member of the Fujitsu staff concerning the importance of achieving high reliability as part of Fujitsu's responsibility to society. At present our staff members are engaged in some 3,200 different reliability themes. During 1979, as an example, we received 47,800 reliability-related proposals as a result of this program, far more than comparable figures for any other maker.

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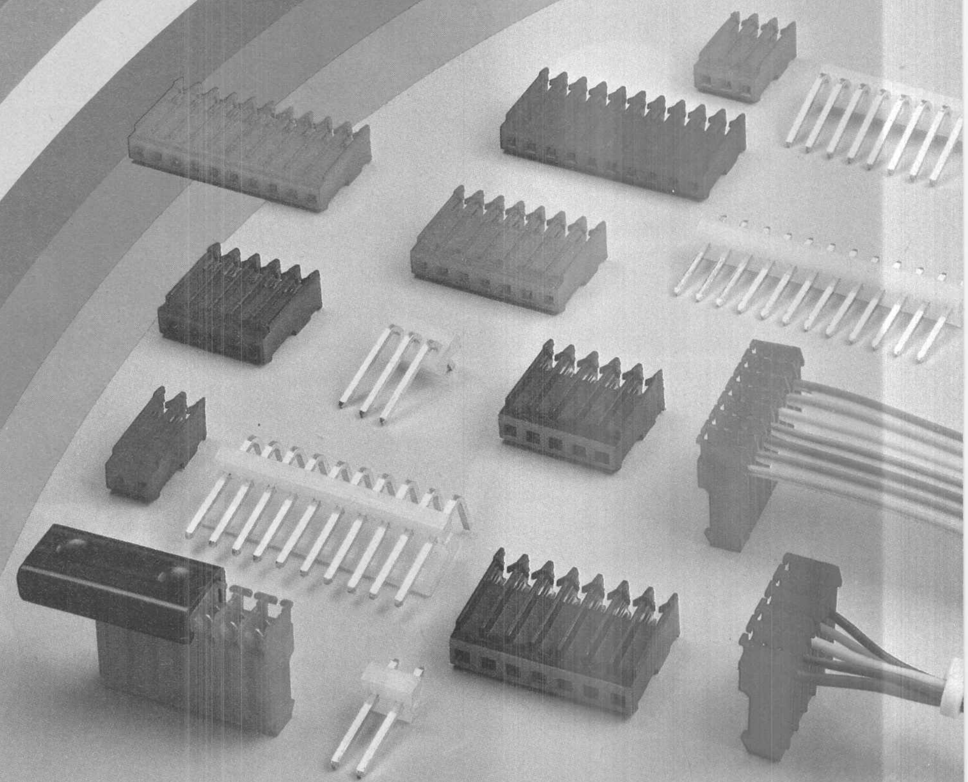
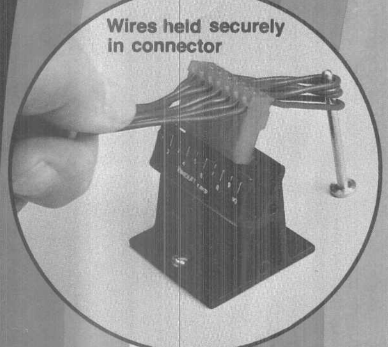


Unique Wire Retention Design Speeds Installation and Reduces Installed Costs



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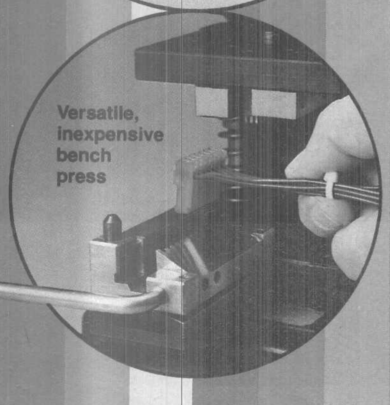

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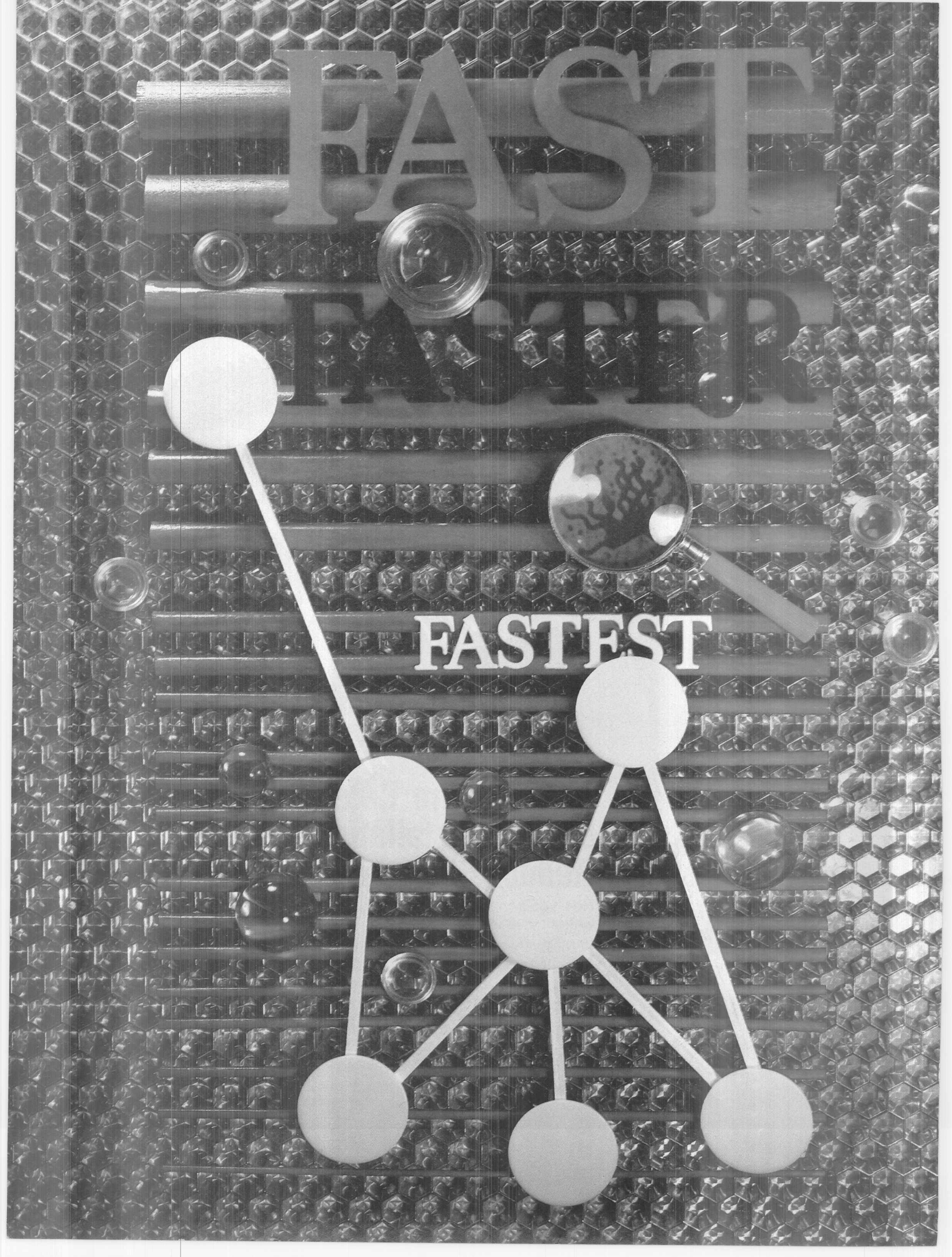

FAST
FASTER
FASTEST

TECHNOLOGY

50 YEARS

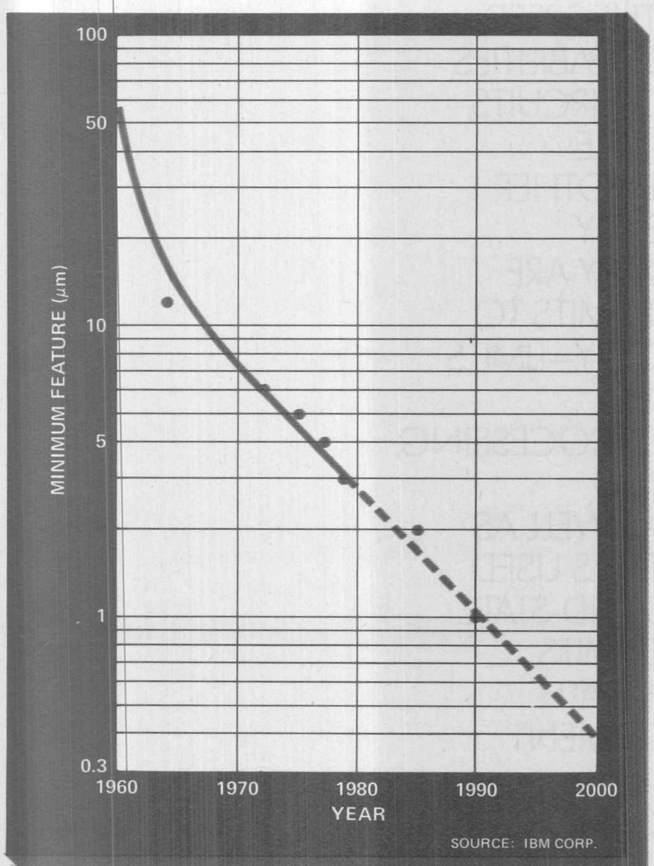
THE DRAMATIC ADVANCES PREDICTED FOR ALL KINDS OF ELECTRONIC EQUIPMENT OVER THE NEXT TWO DECADES WILL DEPEND IN LARGE PART ON EQUALLY DRAMATIC PROGRESS IN SOLID-STATE TECHNOLOGY. AHEAD ARE ENORMOUS INCREASES IN THE SPEED, DENSITY, AND CAPABILITIES OF INTEGRATED CIRCUITS, MAGNETIC-BUBBLE MEMORIES, AND OTHER CHIPS. YET ALREADY PERCEPTIBLE TODAY ARE FUNDAMENTAL LIMITS TO THE TECHNOLOGY—LIMITS INHERENT IN THE LITHOGRAPHIC, PROCESSING, AND PACKAGING TECHNIQUES AS WELL AS THE VERY MATERIALS USED TO PRODUCE SOLID-STATE DEVICES. THESE LIMITS WILL DEFINE THE PATH CIRCUIT DEVELOPMENT TAKES INTO THE NEXT CENTURY.

in the position of a good weekend golfer or tennis player: it is just learning how much of the game remains to be mastered. However remarkable the progress so far, it now appears to be only a foundation for enormous increases in the speed, density, and sophistication of logic and memory circuits.

Why?

As circuits become denser, the cost of performing each function goes down because there are more elements on the chip to share in the cost of processing the entire integrated circuit. This means either that more work can be done for less money or that more power and convenience can be made available for the same money. The recent history of technology indicates, if nothing else, that here are the seeds of change, no less so with ICs than with internal combustion engines. The cheaper and more convenient the tool by which the world's work is performed, the more pervasive its application and the greater the demand for it. And with this demand comes the impetus for refinement of the tool, which, in the case of ICs, is expressed by the compulsion to miniaturize.

State-of-the-art devices today are made with minimum features on the order of 2 micrometers. These will seem gross and clumsy compared with what is coming. Integration levels will be extended at least another order



The big shrink. Despite the challenges associated with reducing the feature sizes in an integrated circuit, dimensions will continue to shrink. If minimum features follow the curve above, the 1-μm barrier for commercial devices will be broken within a decade.

angstroms, where light does not reflect colors, where bacteria and DNA molecules crawl around.

In October 1978, the Department of Defense let loose its program for very high-speed integrated circuitry. One of its goals for the six years following that announcement was to establish a minimum feature of 0.5 μm (500 Å) on devices as large as 400 mils on a side. The latest report from the semiconductor companies: "We can do it."

There will be monolithic megabit random-access memories with data accessible in nanoseconds. Bubble memories with several millions—perhaps billions—of bits will be commonly employed in data-processing equipment. There will be mainframe computers on chips. And beyond that, what is known today as electronics will mesh with and cross-fertilize advances in biology to propagate another revolution that deals with organic molecules and living cells. After all, IC features can already be resolved that are smaller than some bacteria.

It will not be easy. This process of increasing sophistication, which the industry calls integration, is now considered "large scale." That is, semiconductor companies are capable of producing commercial quantities of ICs each of which incorporates 100,000 or so components with minimum dimensions greater than 1 μm. Very large-scale integration, on which the industry now verges, indicates the incorporation of many more than 100,000 components with minimum features near to 1 μm. VLSI will be mastered in the next 20 years, but not without sweat off the industry's brow.

Expensive—very expensive—machines will have to be developed so that commercial devices can be mass-produced using wavelengths shorter than light. Entire new families of resists will have to be concocted that are sensitive to the electron beams, ion beams, and X rays that will form the basis for the new lithography.

Other fundamental limits will be reached but they, too, will be conquered in order. Parasitic capacitances will be lessened with insulating substrates. Heat will be removed with liquids. More levels of on-chip interconnection will be devised. And when the speed of silicon presents a limit, more emphasis will be given to gallium arsenide or other III-V compounds and possibly to Josephson junctions.

VLSI, however, may be limited by a factor that has nothing to do with the technological ability to produce ultraminiature circuits. That factor is demand. If VLSI devices are too specialized or if yield problems are too restrictive, there will be too few customers to direct such components down the so-called learning curve. This problem is more likely to surface with regard to logic devices, as the demand for memory will undoubtedly increase steadily given the broadening application of computers in industrial society. Beyond memory, says Gordon Moore, chairman of Intel Corp., Santa Clara, Calif., it is quite unclear how to take advantage of VLSI. As he points out, the semiconductor industry is not limited by process technology, and the real problem is how best to use that technology's results.

This is a real question. The dynamics of circuit devel-

limits perceived in the laboratory—whether they concern lithography or processes and materials—are likely to be the ones that shape circuit development and with it the architecture of computers.

Lithography, the means by which resist chemicals are exposed to define IC device geometries, is responsible for the minimum dimension possible, and this minimum feature in turn determines the extent to which the devices can be squeezed onto a particular size of substrate.

The overall level of integration is also dependent upon the size of the die and the technology chosen; for example, metal-oxide-semiconductor, or MOS, devices may be packed more densely than bipolar devices. The challenge is producing useful VLSI chips in large numbers at high yields so that they are affordable and reliable.

Experimental devices having submicrometer line widths are already being fabricated at Bell Laboratories in Murray Hill, N. J., International Business Machines Corp.'s Thomas J. Watson Research Center in Yorktown Heights, N. Y., and in the research labs of serious semiconductor companies. In fact, IBM researchers have already realized 80-Å (0.008-μm) lines on thin layers of graphite using electron-beam lithography.

The future course of the minimum feature has been variously predicted. In a paper presented in the fall of 1977 at CompCon 77, the 15th International Conference of the Institute of Electrical and Electronics Engineers' Computer Society, George Marr predicted that minimum features will diminish in accordance with the curve shown the figure on the opposite page. If his assumptions are correct, commercial devices using 1-μm lines may be fabricated by 1990.

Assuming that patterns cannot realistically be resolved that are finer than the wavelength of the light used for exposure, optical lithography loses its effectiveness soon after 1-μm lines are reached. The limit for photolithography is about 0.5-μm, according to M. P. Lepselter, director of the advanced LSI development laboratory at Bell Laboratories in Murray Hill, N. J., and even this requires long exposure to a bright, partially coherent source of deep ultraviolet wavelengths, on the order of 2,000 Å.

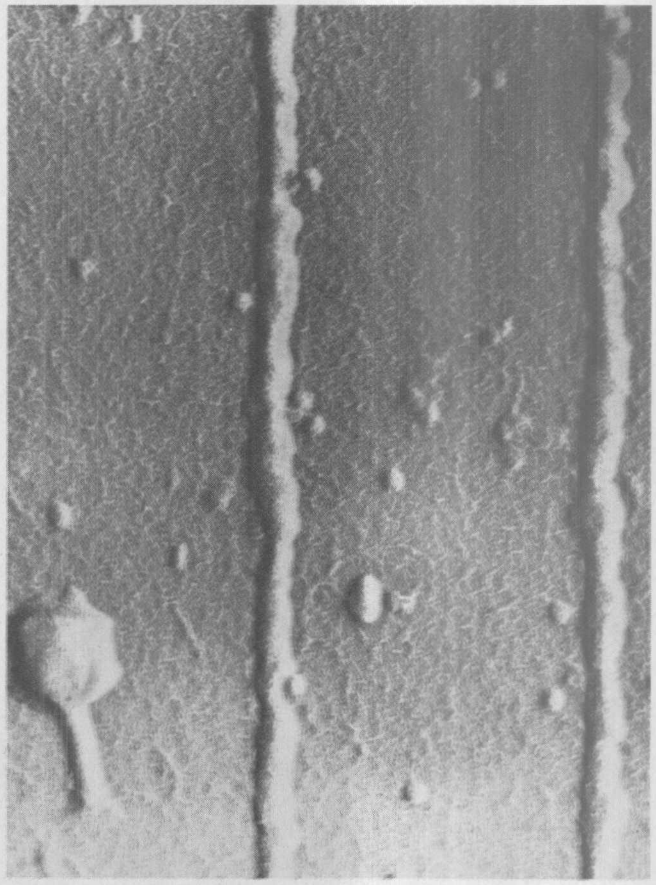
Hence, there was a time when 0.5 μm was considered to be the ultimate resolution and the limiting dimension for LSI circuitry, but this was before it was realized that X rays, electron beams, and ion beams could do better. Although these forms of radiation possess effective wavelengths shorter than those of light, they are not without their own drawbacks, not the least of which is the capital needed to buy the machines to generate the radiation. In fact, some industry observers fear the million-dollar-plus pricetags on such equipment may signal industry maturity—in other words, that only the yet-to-be-determined "big four" semiconductor companies will be able to afford to compete in the various VLSI markets of the future.

The limiting factor with X rays, electron beams, and view individual isolated atoms. Rather, at these higher frequencies, undesirable interactions with particles in the resist and in the silicon substrate come into play. Hence, developing suitable resist chemicals is essential in making these radiation types viable.

With X-ray and electron-beam exposure, secondary electrons are produced in the resist material that have the ability to expose the resist further. Only the side-to-side, or lateral, component of the electron motion has to be minimized, however, since travel directly toward and away from the wafer does not adversely affect resolution.

The lateral range for secondary electron emissions created by X radiation is debatable, but most observers place the distances well below 1,000 Å, more likely between one and several hundred angstroms. X rays are therefore able to resolve features down to at least 0.1 μm. Researchers at the Massachusetts Institute of Technology's Lincoln Laboratory in Lexington, Mass., have recently reported being able to get 200-Å lines using a polyimide mask shadowed with tungsten [*Electronics*, Oct. 11, 1979, p. 92]. These lines are shown in the photograph immediately below, along with a T4 phage virus for comparison.

Secondary electrons also govern the minimum dimen-



Slender. Researchers at MIT's Lincoln Laboratory used a polyimide mask shadowed with tungsten and X-ray lithography to resolve these 200-Å lines of PMMA photoresist on a silicon dioxide substrate. For comparison purposes, a T4 phage virus was placed on the sample.

Harris Technology: A Progress Report

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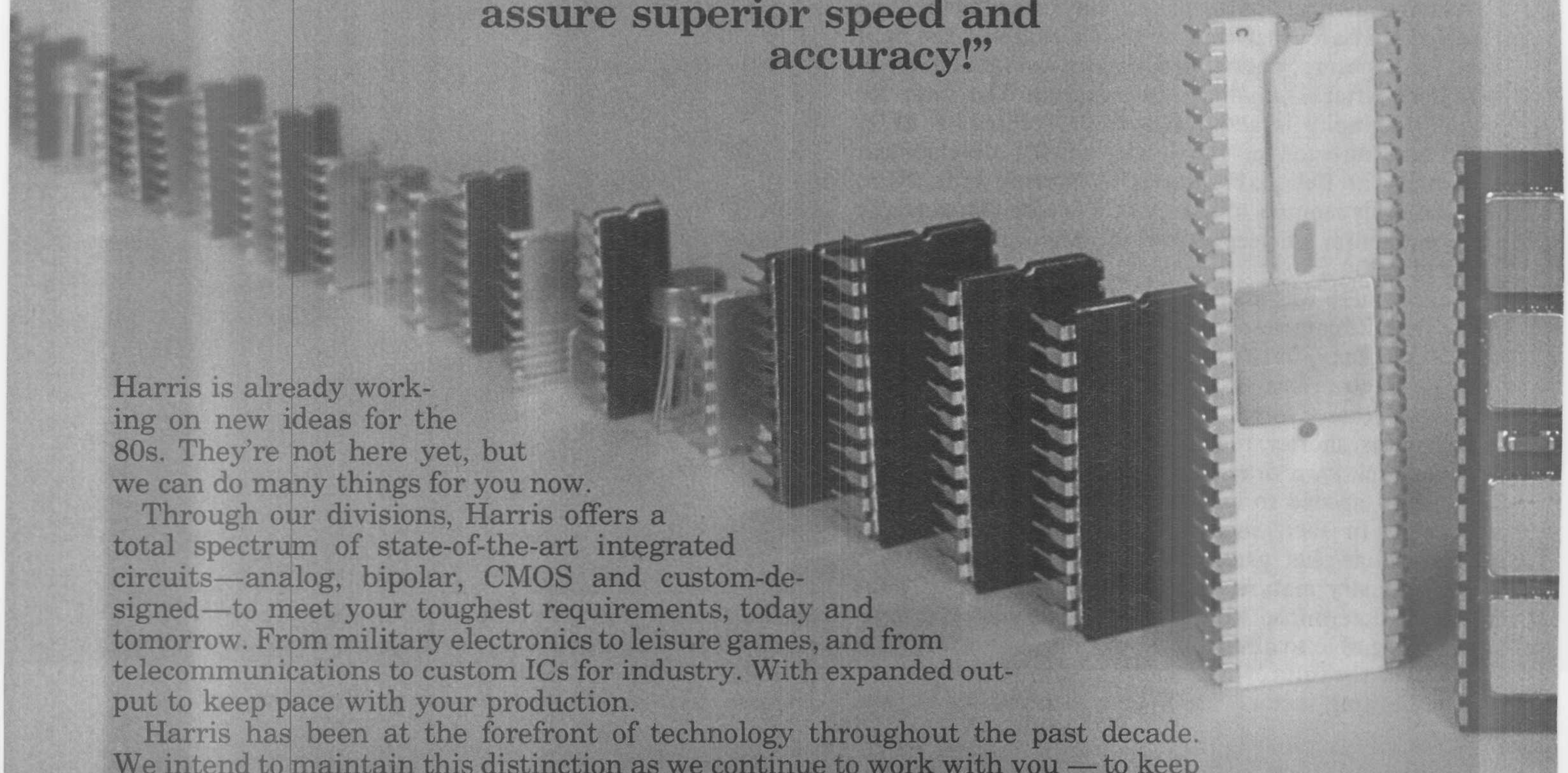

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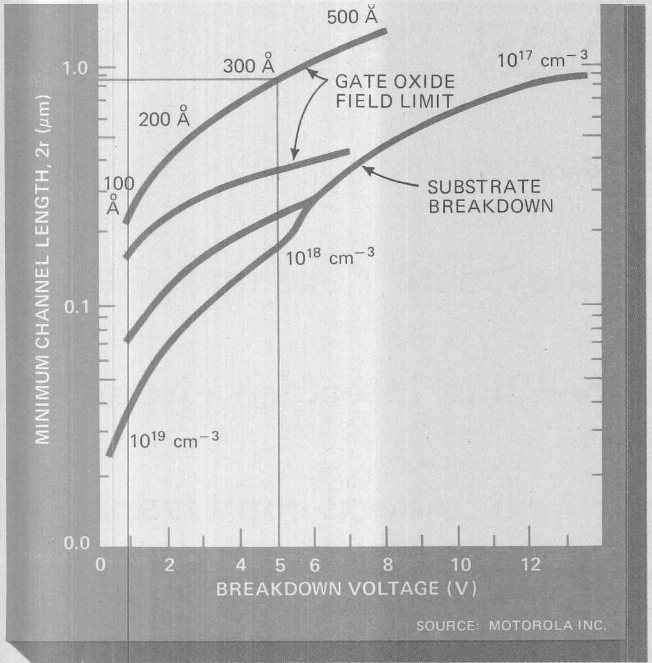
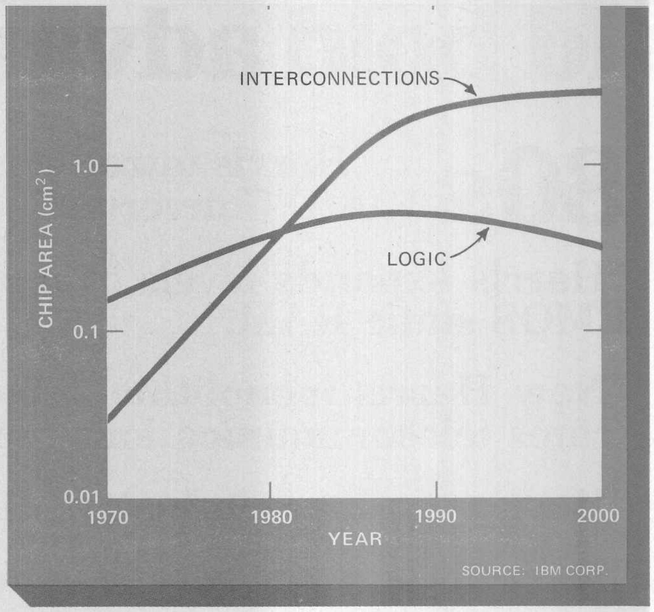


Breakdown. As semiconductor devices shrink, electric fields expand because charge tends to collect at small points. Thus a 300-Å gate should break down at 5 V when the channel is slightly less than 1μm. For VLSI, internal supply voltages will have to be reduced.



Wiring worries. On-chip interconnection of VLSI devices may not seem like a limiting factor, but many semiconductor companies place it at the top of the list of VLSI problems. Interconnections are eating up more space; area for them may equal that for logic very soon.

sion attainable by writing directly on the wafer with an electron beam. The resist can be applied more thinly, but the electron beams introduce a new pitfall: electrons bounce back off of the silicon itself and expose the resist from the opposite direction. The beam current can be lowered to reduce the range of the reflected particles, but at the cost of stretching out the time that is required to expose a spot and hence the total writing time required for the entire wafer.

The ultimate workable resolution attainable with electron-beam lithography is about a third of a micrometer or less. Direct writing on a wafer with an electron beam has another highly desirable advantage: no masks are needed. The main disadvantage, as just noted, is the writing time required. To expose a 4-in. wafer with an electron beam having a 0.1-μm diameter at present takes about 15 minutes. This delay is probably unsuitable for volume production. However, as electron-beam machines will be used to fashion masks for ultraviolet and X-ray exposure, the equipment will be improved. This, coupled with better resist chemicals, will shorten the writing time and electron-beam lithography will enjoy widespread future use for VLSI.

In place of electron beams, ion beams can be used for micrometer and finer geometries. This concept is exciting because the same machine used for exposure can also be used for ion implantation, ion milling, and mask fabrication. But although the technique can realize resolutions on the order of 0.1 μm, the equipment is expensive and proper exposure calls for sensitive resists because the heavier particles have a shallower range. Moreover, it may be difficult to turn such a beam on and off fast enough to ensure tolerable wiring times.

The time for ion-beam (and electron-beam) exposure can be reduced by using parallel stationary beams (instead of a single, moving beam) and passing them through a mask, just as in X-ray and optical lithography. Preparing the necessary mask is of course tricky, as portions of it need to absorb radiation of a much higher frequency than light, while at other points the rays must pass through easily. And, as usual, the resultant resolution is dependent upon mask-to-wafer spacing. Various companies are toying with parallel-beam exposure, and their conclusions are optimistic; line widths definitely less than 0.5 μm are achievable with masked electron beams or ion beams.

Even if extremely small geometries are defined through exposure, developing the resists creates other technical difficulties. The semiconductor industry today is based almost entirely on what is termed wet processing—that is, the use of liquid developers to induce chemical changes in the exposed resist so that it can be etched.

The wet chemical development process has many idiosyncrasies, says George Heilmeier, vice president for corporate research, development, and engineering at Texas Instruments Inc. in Dallas. One undesirable effect is that the wet chemicals may be absorbed by the resist and thus may undercut it or cause it to swell or both. For the most part, says Heilmeier, wet chemical etching is "an empirical process that is fairly difficult to control."

Its uncontrollability has led researchers and industry to focus on dry processing, which involves the use of plasma as the etchant. "With dry processing, it is possible to etch very, very steep walls and finer geometries in materials without undercutting," says Heilmeier. Plasma

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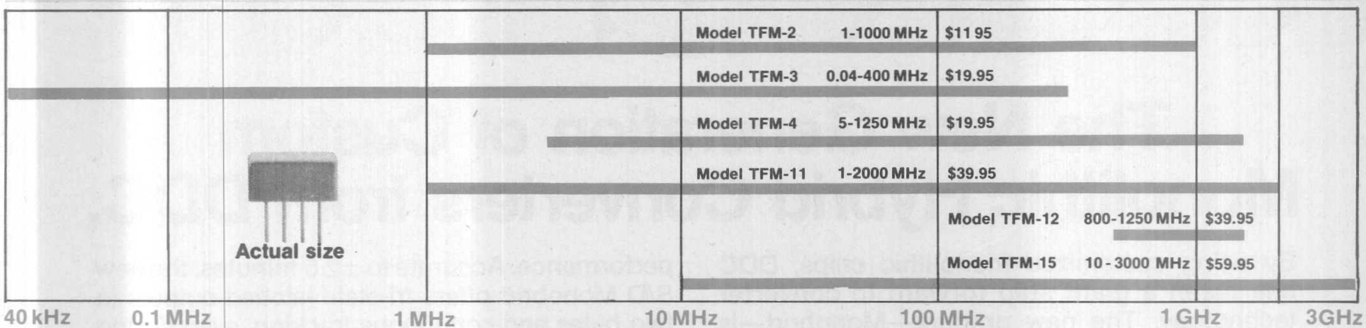

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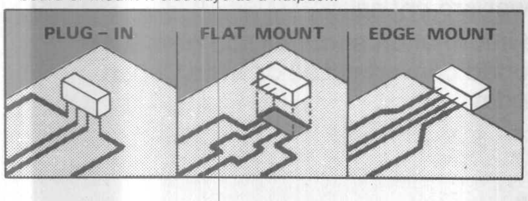

Model	Frequency, MHz			Conv. loss, dB				Isolation, dB												Cost	
				One Octave From Band Edge		Total Range		Lower Band Edge To one Decade Higher				Mid Range				Upper Band Edge To Octave Lower					
								LO-RF		LO-IF		LO-RF		LO-IF		LO-RF		LO-IF			
Model No.	LO	RF	IF	Typ.	Max.	Typ.	Max.	Typ.	Min.	Typ.	Min.	Typ.	Min.	Typ.	Min.	Typ.	Min.	Typ.	Min.	Quantity	Price
TFM-2	1-1000	1-1000	DC-1000	6.0	7.5	7.0	8.5	50	45	45	40	40	25	35	25	30	25	25	20	6-49	$11.95
TFM-3	.04-400	.04-400	DC-400	5.3	7.0	6.0	8.0	60	50	55	40	50	35	45	30	35	25	35	25	5-49	$19.95
TFM-4	5-1250	5-1250	DC-1250	6.0	7.5	7.5	8.5	50	45	45	40	40	30	35	25	30	25	25	20	5-49	$19.95
TFM-11	1-2000	1-2000	5-600	7.0	8.5	7.5	9.0	50	45	45	40	35	25	27	20	25	20	25	20	1-24	$39.95
TFM-12	800-1250	800-1250	50-90	—	—	6.0	7.5	35	25	30	20	35	25	30	20	35	25	30	20	1-24	$39.95
*TFM-15	10-3000	10-3000	10-800	6.3	7.5	6.5	9.0	30	20	30	20	30	20	30	20	30	20	30	20	1-9	$59.95

Signal. 1 dB compression level +1 dBm. Impedance, all ports 50 ohms. Total input power 50 mW. Total input, current peak 40 mA. Operating and storage temperature −55° C to +100° C. Pin temperature 510° F (10 sec).
*LO power +10 dBm, 1 dB compression +5 dBm

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can be used for much more than resist etching; it can be used to etch silicon and metals as well.

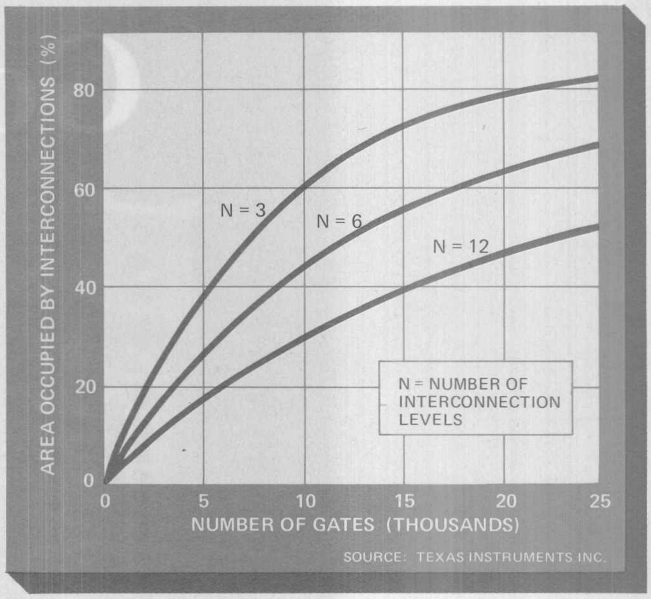
Even if micrometer and submicrometer geometries are exposed and developed, there is no guarantee that chips built to these specifications can be mass-produced. Even before the limits of lithography are reached, device-related problems will need to be subdued. The industry will need to understand and model the behavior of submicrometer structures, find the means to interconnect the enormous numbers of devices that will be fabricated on a single substrate, and develop suitable packages to carry heat away fast enough to make way for high-speed operation.

It is unfortunate, but as dimensions become smaller, electric fields tend to increase because charge tends to collect at small points. If MOS transistors are scaled down enough, the semiconductor junction and gate oxide can both break down. The distance between the source and drain must be greater than the sum of the widths of the depletion regions associated with each of these electrodes if transistor action is not to be lost. And although heavy doping can minimize the degree to which the depletion regions encroach upon the channel, it increases the electric field presented to the gate oxide.

According to William Howard, director of technology and planning for Motorola Inc., Phoenix, "Breakdown is a fundamental problem. As things get smaller, the higher the electric field becomes, and sometime during HMOS [scaled-down and hence high-performance MOS], we're going to have to address the power supply voltage situation." Howard does not claim to know the ultimate solution, but he makes two suggestions: "We could ask customers to adopt a lower voltage, like 2 to 3 V, or we could use on-chip regulation." In either case, the voltage presented to the transistors would be reduced. Referring to Fig. 3, with 2 V applied to the gate, the channel length could be reduced to 0.3 μm. It should be noted that some state-of-the-art MOS devices, like 64-K random-access memories, already operate at internal voltages that are less than +5 V.

The electric fields in a device must be kept down for another reason besides breakdown. If electrons take on enough energy, they may be able to escape the silicon, penetrate the oxide, and become trapped there. As these "hot" electrons, as they are called, carry with them a negative charge, the device's turn-on (or turn-off) threshold voltage can shift. Furthermore, it is expected that advanced processing techniques, such as electron-beam exposure and dry plasma etching, will compound the problem because the higher energies generated by such equipment could create more electron-trapping sites in the gate insulator.

Interconnecting VLSI devices may not seem like a limiting factor, but Motorola, for one, places it at the top of its list of VLSI problems. As a die is stocked with more and more devices, the device connection problem becomes more acute. The interconnections use up more and more of the chip area, and the returns from further integration, especially those of logic circuitry, quickly diminish. Robert Keyes, a researcher at IBM Corp.'s Watson research center, predicts that the area required to connect logic will grow more rapidly than chip area and that the two areas will in fact be about equal in 1980.



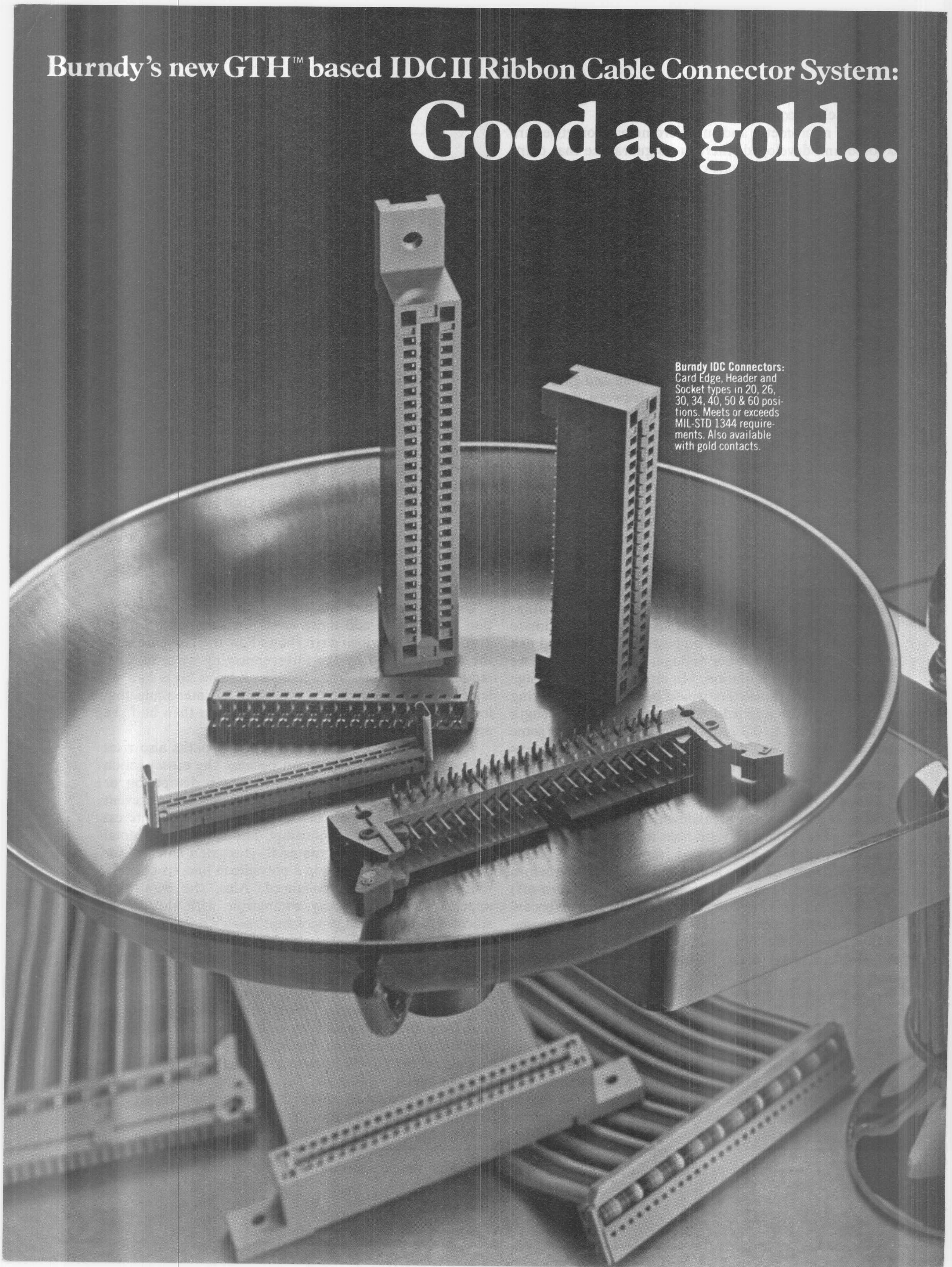
Solution. Although on-chip wiring is smothering area that would otherwise be used for logic, there are solutions. One is to increase the number of interconnection levels. But even with 12 levels, wiring will make up half the area of a device having 25,000 gates.

One way to reduce the area required for interconnection is simply to add more levels for this purpose. The graph on the previous page shows how the percentage of the area occupied by the interconnecting wires may be reduced by moving from today's 3 levels to 6 and 12 levels. As the graph shows, even with 12 interconnecting levels, the wiring will still constitute more than half the area of a chip with only 25,000 gates.

The resistance of the interconnecting paths also rises as geometries are scaled down because the cross section of the wiring is reduced. Higher power dissipation or lower speed or both may result, and the desire to prevent such undesirable effects has led to an increased interest in the use of laser annealing and refractory metal silicides. When such a material—tungsten silicide, for example—is deposited atop a polysilicon line, its conductivity is dramatically enhanced. Also, the deposition appears to be completely compatible with the use of silicon gates and VLSI processing.

As if the design of VLSI chips is not already beset with challenges, packaging will not be easy either. "The ultimate limit with VLSI may be getting the signals in and out," says Motorola's Howard. Even if, through on-chip decoding or multiplexing, the number of connections to and from the chip could be kept reasonable, "thermal barriers will come about due to limitations in our ability to conduct heat away from semiconductor devices," says TI's Heilmeier, adding that ". . . no matter how fine we make the geometries, thermal limits are going to come into play long before the physical limits, the processing limits, or the lithography limits."

Switching from air cooling to liquid cooling can postpone this temperature problem for a long time. But for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After Durability (25 Cycles)	5.73	7.28	6.32
After Durability (50 Cycles)	6.39	12.43	7.84
Test Group 2			
Initial C.R.	4.74	6.42	5.23
After Vibration & Shock	5.06	7.69	5.55
After Humidity	5.18	14.50	6.46

Conditioning	Milliohms Min.	Max.	Avg.
Test Group 3			
Initial C.R.	4.83	5.62	5.07
After Thermal Shock	5.08	6.61	5.55
Test Group 4			
Insulation Resistance (1,000 VAC for 1 Minute)	$>7x10^4$	$>8x10^4$	$>7.5x10^4$
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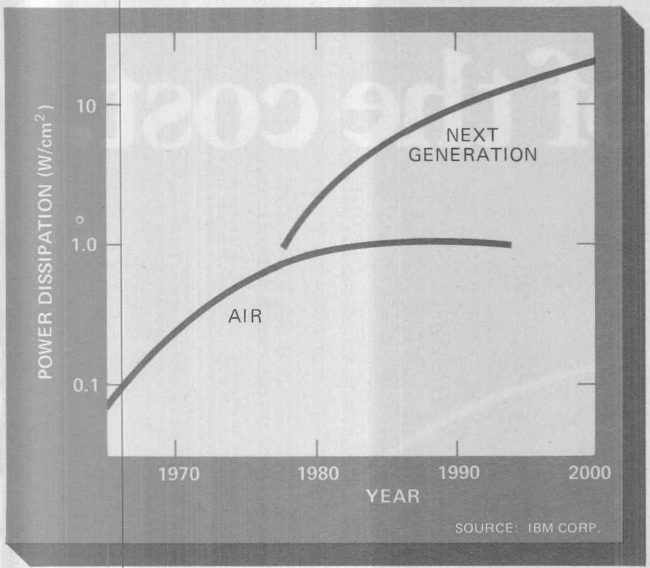

Cool it. Another challenge for VLSI is packaging so as to remove the heat generated. Air-cooled packages are capable of dissipating roughly 1 watt without a heat sink. Liquid cooling can be used, though, to raise the limit to about 20 watts per square centimeter.

the next generation of devices, liquid cooling has the ability to raise the power density significantly. The limit with liquid cooling is about 20 watts per square centimeter, at which point Freon will boil. Another solution is to switch to a lower-power technology such as complementary MOS. Many companies are busy investigating this prospect.

Having somehow attained the ability to produce and reproduce very tight circuit tolerances, a semiconductor company is next faced with a choice between technologies. For VLSI, the technology must meet at least a dual requirement: very high packing density and very high speed. As the table shows, the technologies available are many. And this table does not include nonsilicon approaches to logic or memory, such as the use of gallium arsenide or other III-V semiconductor compounds, garnet for magnetic bubbles, and niobium or lead alloys for Josephson junctions.

The primary semiconductor candidates for VLSI are integrated injection logic (or some other form of current-mode logic), n-channel MOS, complementary-MOS, and gallium arsenide. Also, many if not all of these will be fabricated on some form of insulating substrate.

The future of bipolar integration is difficult to predict, as bipolar devices are in general not easily scaled down. Bipolar transistors demand more processing steps than do MOS structures, and too many of these steps involve the introduction of impurities, either by diffusion or through ion implantation. Also, bipolar devices tend to dissipate more power than other technologies, a drawback that so far has kept bipolar integration at relatively modest levels.

On the other hand, integrated injection logic, with its low power-delay product, is one bipolar form that could be made compatible with VLSI processing. As for complexity, current processing and packaging limit the gate count to some 3,000 gates or less. But, according to Thomas Longo, vice president and chief technical officer for Fairchild Camera & Instrument Corp., Mountain View, Calif., it is reasonable to expect that I^2L complexity will double every two years.

MOS technologies show much promise for VLSI for many reasons. Device designers have been extremely ingenious at improving speed and density even without adjusting minimum features. MOS devices need little power and are self-isolating; thus, charge can be stored on their capacitive gates, making dynamic logic and memories possible.

Predictions about complementary-MOS point to its widespread use for VLSI circuitry, but not necessarily for memories. "C-MOS will play a role," comments Robert C. Fletcher, executive director of integrated circuits development at Bell Laboratories. "While bipolar and straight MOS are coming closer to the old power versus integration-level dichotomy, there are certain applications where power will be the limiting factor." Fletcher adds that although C-MOS has quite a bit of potential because of its lower power usage, it probably will not be used for memories because it incurs too much of a penalty in chip area. Federico Faggin, president of Zilog Inc., Cupertino, Calif., is in agreement. He says, "You have to use C-MOS above a certain level of complexity—except in memories."

Joseph Borel, director of the Laboratoire de Microélectronique Appliquée in Grenoble, France, makes similar observations. "Power consumption is likely to force the development of a kind of super C-MOS with greatly increased density," he comments. Borel is also a believer in silicon on sapphire because of its immunity to the parasitic effects that, as he notes, cannot be avoided in bipolar devices or MOS devices made in bulk silicon.

Sapphire does indeed make a nice bed for silicon circuitry because the two crystal lattices match. However, the cost of the sapphire remains a limiting factor; after all, natural sapphire is precious. To combat this cost, RCA Corp.'s Solid State division in Somerville, N. J., has been trying to pull sapphire ribbons from the melt. However, it has still not succeeded in bringing the cost of sapphire-based devices down to those fabricated in bulk silicon. Motorola's Bill Howard agrees that an insulating substrate could point the way to lower power consumption, fewer parasitic effects, and high-speed VLSI circuits. But he refrains from saying that sapphire is the right material; indeed, he jokingly refers to SOS as "silicon on something else."

An indirect way to realize single-crystal silicon on an insulating substrate is to laser-anneal polycrystalline material on an insulating substrate. Many researchers are exploring this possibility and obtaining promising results. Polysilicon grown on silicon oxide or nitride has been laser-annealed and devices with good characteristics have been fabricated in the large-grained material. More importantly, however, because polysilicon can be grown over oxides and vice versa, the technique may mean the development of truly three-dimensional structures, as opposed to the planar

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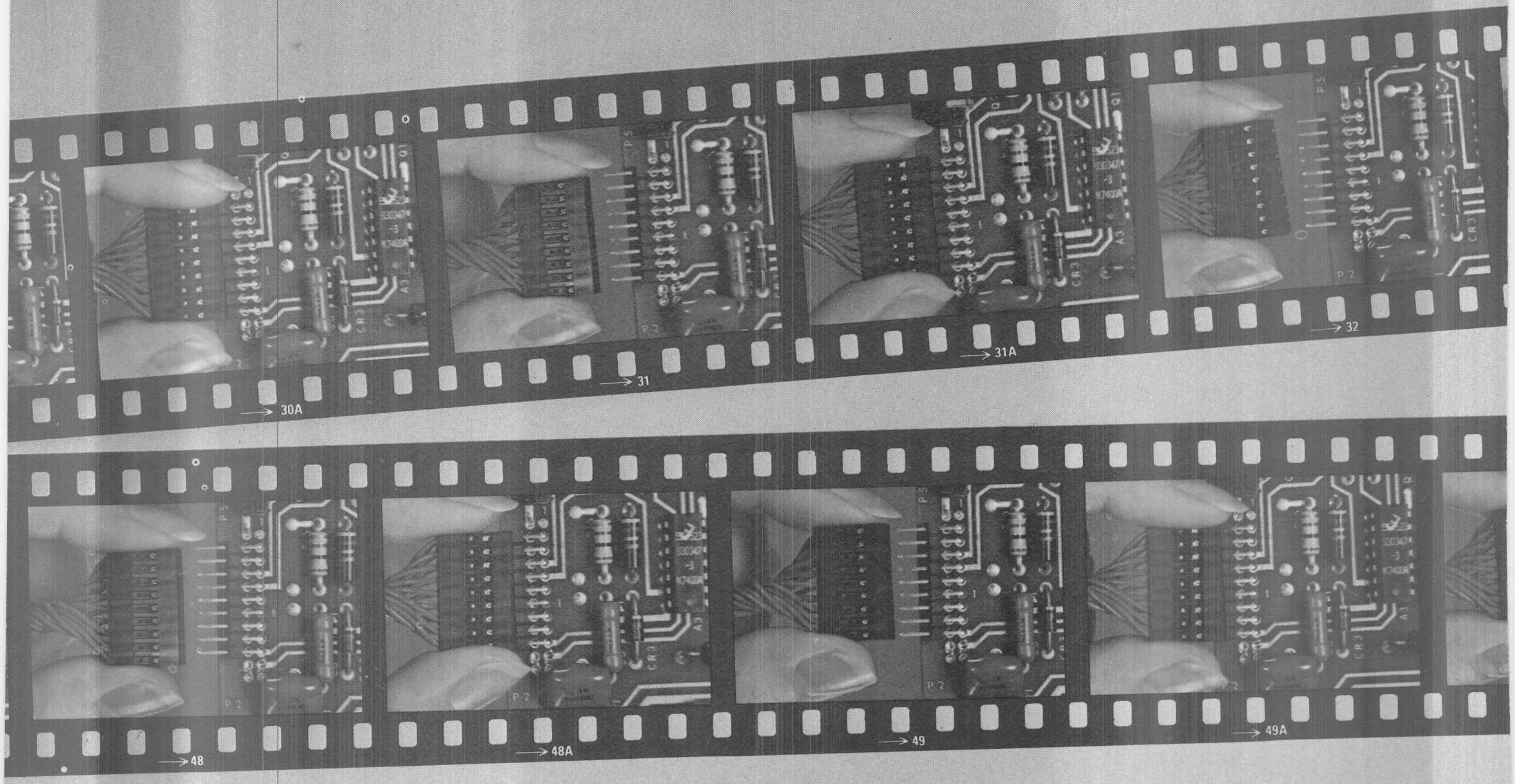

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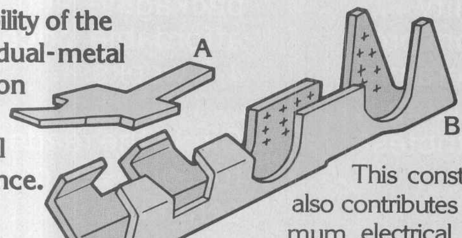

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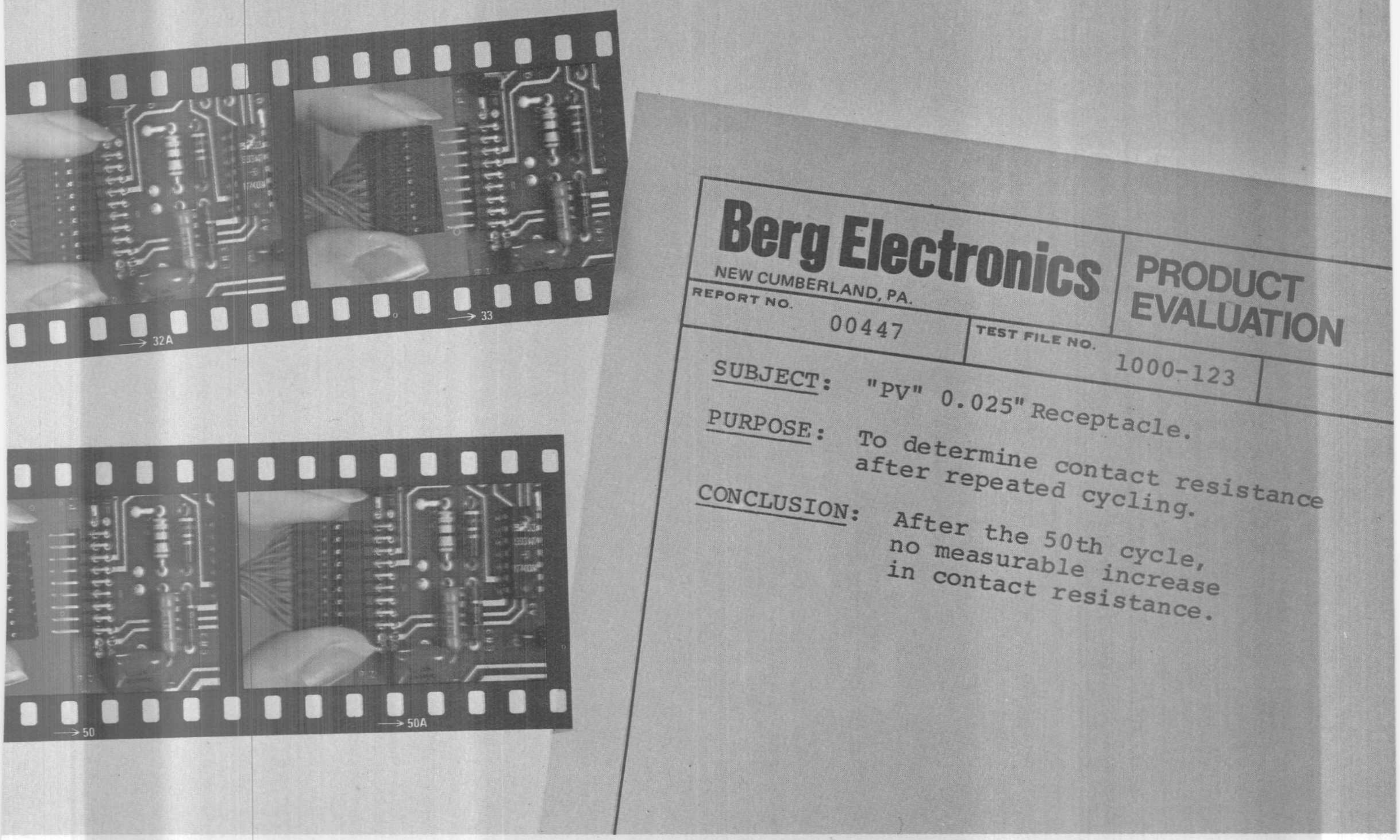

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TECHNOLOGY CHOICES

Property	Current technology, 1979 – 1980								Future, 1985 – 1990	
	Bipolar				MOS				Silicon on sapphire	Gallium arsenide
	TTL	LS TTL	ECL	I^2L	p-MOS	n-MOS	C-MOS(bulk)	C-MOS(SOS)		
Process complexity (number of processing steps)	18 to 22*	18 to 23*	19 to 23*	13 to 17	8 to 14	9 to 15	14 to 17	14 to 20	14 to 20	16
Logic complexity (number of components per two-input gate)	12	12	8	3 to 4	3	3	4	4	3 to 4	2
Packing density (gates/mm²)	10 to 20	20 to 40	15 to 20	75 to 150	75 to 150	100 to 200	40 to 90	100 to 200	200 to 500	300 to 1,000
Propagation delay (ns)(typical value)	6 to 30 (10)	2 to 10 (5)	0.7 to 2 (2)	7 to 50 (20)	30 to 200 (100)	4 to 25 (15)	10 to 35 (20)	4 to 20 (10)	0.2 to 0.4 (0.3)	0.05 to 0.1 (0.07)
Speed power product (pJ)	30 to 150	10 to 60	15 to 80	0.2 to 2.0	50 to 500	5 to 50	2 to 40	0.5 to 30	0.1 to 0.2	0.01 to 0.1
Probability of improvement	low	low	low	moderate	low	high	moderate	high	high	high

*Oxide isolation steps are extra

Source: Lockheed Microelectronics Center

devices almost universally used today.

One technology that will definitely be pushed into VLSI is n-channel MOS. Through refinements in circuit design and processing, the complexity of n-channel devices has neatly conformed to Moore's law. This law states that semiconductor device complexity doubles every year. It gets its name from Intel's chairman Gordon Moore, who is credited with having first predicted this relationship.

However, this law is soon to be broken. Due to problems in both lithography and processing, the density of all forms of MOS, including n-channel, is expected to grow less fast and to begin to double only about every two years.

The enormous quantities of n-MOS static and dynamic RAMs shipped annually are a testament to that technology's success—a success that will continue and bring 256-K and 1-megabit dynamic memories in the 1980s.

For packaging considerations, this will require an order of magnitude decrease in the power dissipation per cell down to about 1 microwatt. Most chip companies feel this can be done. And of course, the cell area will need to be very tiny for a high yield.

There are many approaches to very small n-MOS dynamic memory cells. One is quadruply-self-aligned MOS, from the Japan Cooperative Laboratories in Kawasaki. This scheme, discussed at the 1979 International Electron Devices Meeting, lines up the fabrication of the polysilicon gates, source and drain diffusions, deep junction areas, and interconnection areas to attain what the Japanese researchers feel is the smallest dynamic cell possible: 2 by 3 μm. Thus, a monolithic megabit chip could conceivably be made with this technology on a substrate not much larger than 6 square millimeters.

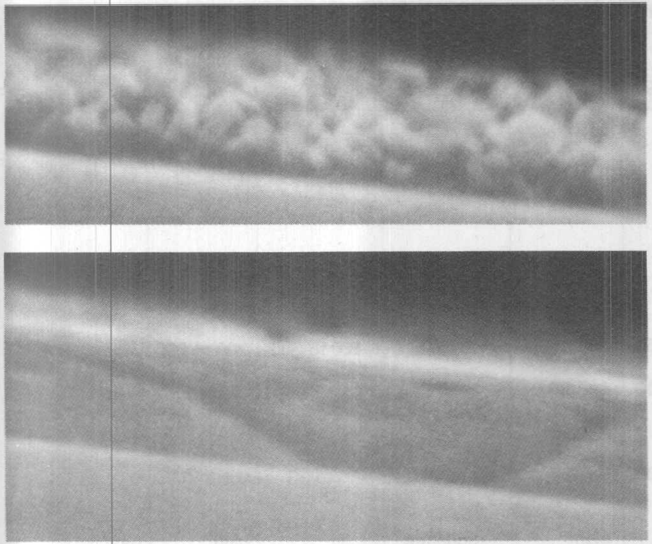
Another approach to the tiniest dynamic RAM cell comes from Texas Instruments: the taper-isolated cell. The cell can store a 1 or 0 without the need for a storage capacitor. It uses a single-polysilicon process, and n- and p-type implants are adjusted to form a potential distribution that resembles a bowling alley. This distribution is able to trap a packet of holes, and the presence or absence of the holes reflects a 1 or a 0, respectively. Thus, a taper-isolated cell can be made 30% smaller than a one-transistor cell having a capacitor.

If the taper-isolated approach could somehow be applied to the quadruply-self-aligned cell, the resulting cell area would be a mere 1.8 μm^2. This figure is very close to fundamental physical limits, according to Arnold Reisman of IBM's Watson research center. He says that computer simulations show that at about a 0.8-μm gate width there is enough noise to keep the FET switch on all the time.

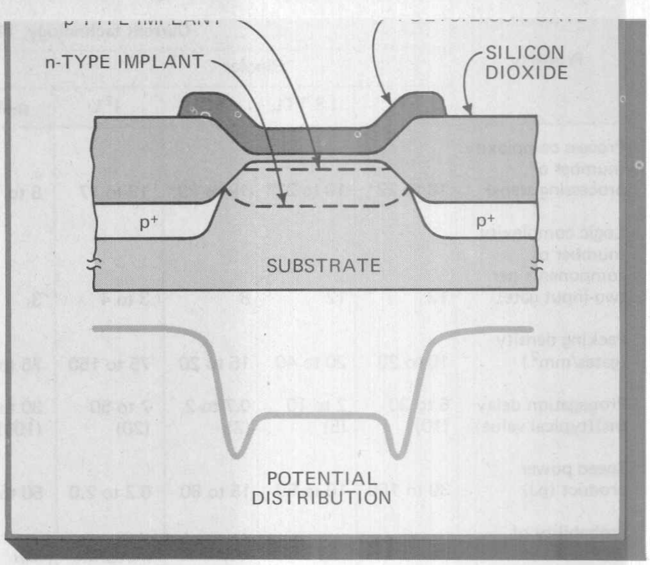
This limit can be circumvented by cooling down the chip, but another solution is more likely before that happens: static cells will be used instead. Static cells have no gate charge that constantly needs refreshing, so that thermal noise affects them much less. Thus, before the year 2000, a big switch might be made from dynamic RAMs to statics.

Read-only memories, of course, because they are not written electrically, can be made even smaller than RAMs. "The ROM is really an exciting kind of product that hasn't gotten the attention it deserves," states J. Leland Seely, vice president and manager of corporate research and development at American Microsystems, Inc., Santa Clara, Calif. "You can really reduce it to a crosspoint—the intersection of two lines—so a cell area of 1.6 μm^2 is a realistic minimum value."

But Seely tacks various caveats on to that prediction. For instance, the sense amplifiers have to "switch from sensing voltage to sensing current," and for high speed, the resistivity of the interconnections have to be considered. "You start to speak of exotic processing technolo-



Soothe it. Is it possible to build three-dimensional ICs? Sure, and laser-annealed polysilicon may hold the key. In (a), polysilicon on silicon dioxide is shown before annealing; note the rough, pebbly texture. In (b), that polysilicon is annealed; it is much smoother.



No capacitor. Present random-access memories use only one transistor per cell, but a capacitor is also present. Various approaches have been tried to drop that capacitor; this taper-isolated cell is one of them. The potential distribution traps charge.

gies, such as laser annealing," he warns.

Other changes are in store for memories, be they RAMs or ROMs. Approaches like the taper isolation will allow RAMs to sneak up on the densities of ROMs. But future RAMs will also become similar to ROMs in terms of organization. "In previous generation jumps, we always knew how the next device would be organized; 16-K-by-1-bit, 64-K-by-1-bit, etc.," says TI's Heilmeier. "But for the first time, the issue of what comes next isn't a linear projection any more." Heilmeier points to "interesting new memory organizations" for the microprocessor market for RAMs, which could swell to match the mainframe market in the 1980s. Hence, he sees byte- and word-oriented devices.

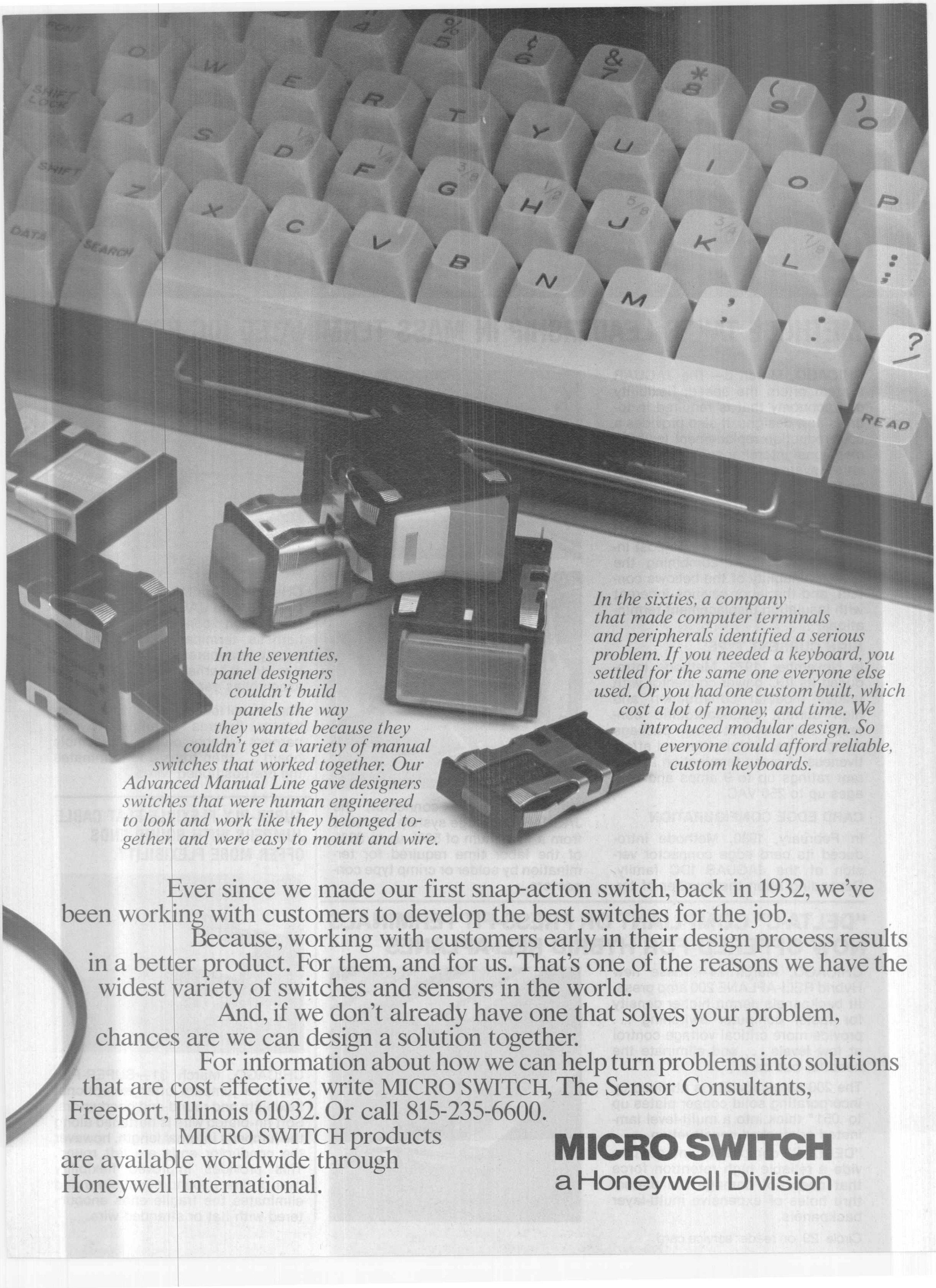
Another reason to steer clear of the by-1-bit organizations is that chip-testing times become intolerably long. "How do you test a 500-K-by-1-bit chip?" Heilmeier asks. He predicts that in general, VLSI memory components will be optimized for the system they are being designed for. "There are certain memory-management schemes that we do today off chip in software," he says, adding that "even though you may have the ability to build, say, a half-megabit RAM, you may choose to use up some of that capability in order to add things like self-test fault-tolerance and memory-management features on chip."

One reason to adopt self-testing for fault tolerance is also another reason to switch to static devices. The reason is radiation, such as that embodied by alpha particles. Static cells are less susceptible to the effects of radiation, and many feel the situation will get worse before it gets better. From Gordon Hoffman, manager for memory components and systems at Mostek Corp., Carrollton, Texas, comes this ominous warning: "What I'm afraid of is that, as we get into smaller dimensions, we'll get to other kinds of radiation—maybe cosmic rays. If the particles are energetic and are not stopped by organic coatings, we're in trouble." Hoffman is not the only one to bring up cosmic radiation, but the general consensus is that radiation will not be a limiting factor. "We will solve the alpha problem as we solve the problems of cosmic and other rays," says Zilog's Faggin. "Silicon processing, packaging, and design all have to converge to solve the [alpha radiation] problem," says Intel Corp. vice president, Leslie L. Vadasz. "Error correction at the systems level would make it a nonproblem, and the same thing would apply to the memory system on a chip."

Advances will also be made with regard to nonvolatile forms of memory, especially the electrically erasable variety. The most promising attempt thus far comes from Xicor Inc., Sunnyvale, Calif. Xicor's nonvolatile RAM uses enhanced electron tunneling to and from a floating polysilicon gate to store 1s and 0s even after the power has been removed. But unlike all other previous approaches, Xicor's memory needs only one supply (+5 V) for all operations and the kind of processing employed in standard n-channel polysilicon gate; no special nitrides are needed nor expensive packages containing quartz windows to let in the erasing energy. Thus this type of memory can be included on the same substrate that holds a microprocessor, and laser annealing might be applied to the cell to stack the polysilicon element vertically for a dramatic reduction in size.

There is a very good reason why silicon is used to fabricate electronic components. Next to oxygen, it is the most abundant material on the earth's surface. More important, it is very easy to grow insulating layers on silicon. But the impulse to higher performance—faster and denser devices—demands that the industry go beyond silicon in both logic and memory device development. For silicon is to semiconductor tech-


Most of our products started as someone else's problems.
Even our first switch solved a problem. A small company that made incubators for poultry couldn't get the precision they needed in a thermostatic switch. Chickens weren't hatching on time. So we made them a snap-action switch they could count on. And their customers could count on chickens.
Recently, a major manufacturer of machine tools needed a solid state proximity sensor. However, this one also had to be rugged, easy to mount and wire, and interchangeable with a traditional limit switch. So we developed the new 2-wire AC proximity switch.
Perhaps you remember when the government first cracked down on fuel efficiency in car ignition and timing systems. One auto manufacturer came to us with the problem. The result was our solid state Hall effect vane sensor. A sensor that functioned efficiently and reliably without adjustment, even in the worst driving conditions.


In the sixties, a company that made computer terminals and peripherals identified a serious problem. If you needed a keyboard, you settled for the same one everyone else used. Or you had one custom built, which cost a lot of money, and time. We introduced modular design. So everyone could afford reliable, custom keyboards.
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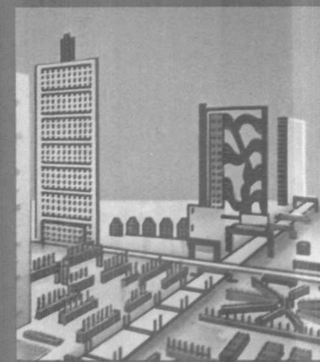


METHODE TAKES LEADERSHIP IN MASS TERMINATED IDC PRODUCTS.

CHICAGO, March 3—The JAGUAR system offers the speed, flexibility and economy that is required in today's new designs. It also provides a cost reduction replacement (with dimensional interchangeability) for existing systems with no sacrifice in performance or reliability.

WIRE-TO-POST SYSTEM

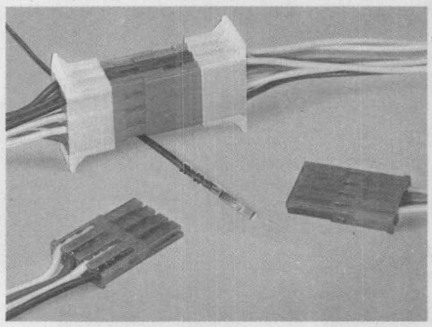
The original Methode JAGUAR Series is a complete wire-to-post interconnect system combining the proven reliability of the bellows contact, and the labor savings inherent with insulation displacement terminations.

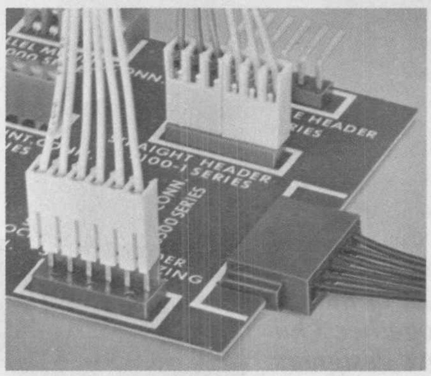
HIGH CURRENT TYPE

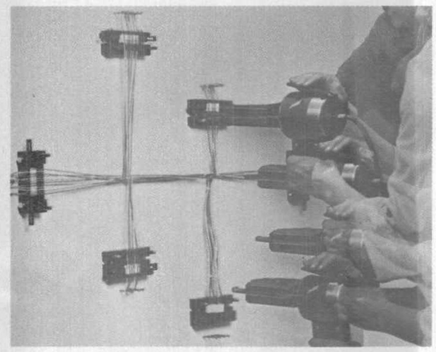
In November, 1979, Methode introduced its IDC power connector with unique modular construction and high current hermaphroditic contacts. For the first time, package designers can obtain the cost effectiveness of mass termination at current ratings up to 9 amps and voltages up to 250 VAC.

CARD EDGE CONFIGURATION

In February, 1980, Methode introduced its card edge connector version of the JAGUAR IDC family. Depending upon the number of terminations on the connector, the JAGUAR card edge system can save from a mimimum of 50% up to 90% of the labor time required for termination by solder or crimp type connectors.







CHICAGO, April 7—Developed for use with the JAGUAR Series mass termination connectors, our new harness terminator gun simultaneously terminates 2 through 24 position circuit harnesses at a rate of 500 assemblies per hour.

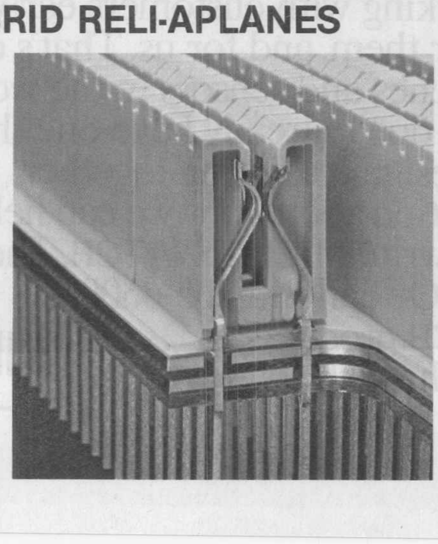
The air tool locks easily into IDC connector fixtures arranged to the harness shape on the assembly board . . . then trims and terminates the pre-positioned wires.

"DELTA-C" COMPLIANT OR PRESS-FIT TERMINALS NOW OFFERED FOR HYBRID RELI-APLANES

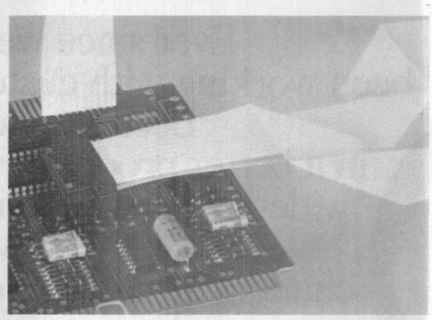
CHICAGO, March 24—These new Hybrid RELI-APLANE 200 amp press-fit backpanels permit higher density for faster computer switching . . . provide more critical voltage control at low levels . . . and eliminate the need for bus bars.

The 200 amp capacity is attained by incorporating solid copper plates up to .051″ thick into a multi-level laminated or stacked construction.

"DELTA-C" compliant contacts provide a reliable high retention force that does not damage the plated-thru holes of expensive multi-layer backpanels.

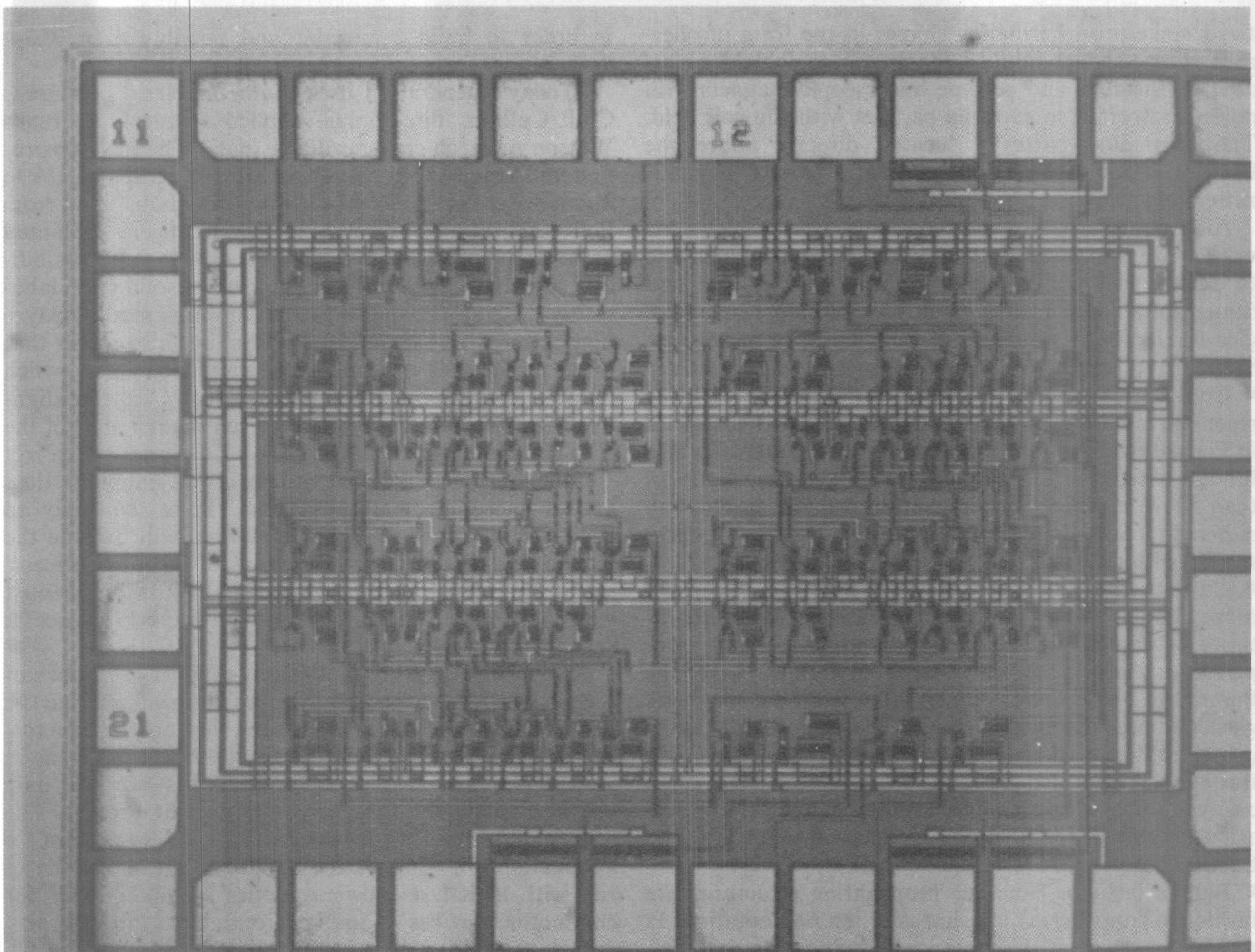


SUPER-PLY FLEXIBLE FLAT CABLE JUMPERS WITH ROUND ENDS OFFER MORE FLEXIBILITY.



CHICAGO, March 31—SUPER-PLY flat wire jumpers offer exceptional flexibility and round-end conductors. Soft tin-plated wire is flattened along the jumper's internal length, however the conductor ends are left round. This provides improved flexibility over ordinary round conductors and eliminates the fragile ends encountered with flat or stranded wire.

Circle 29 on reader service card



Gallium arsenide. To go beyond the speed of silicon, gallium arsenide with its enhanced mobility is one material to use. It has its own set of challenges, one of which is the inability to oxidize it for insulating layers. Still, circuits like this counter have been made.

nology what iron and steel have been to modern metallurgy—enormously useful foundations that served well for relatively unsophisticated demands.

Already silicon has been superseded not simply in laboratory experiment but for commercial production of memory devices with capacities at least four times higher than anything so far realized with silicon: the magnetic-bubble memory. Other technologies are on the horizon that will similarly accelerate speed of computation, although their role in commercial development is as yet uncertain.

These technologies, which include the use of gallium arsenide and the superconducting materials of Josephson junctions, are constrained at present by processing and operating costs. For example, gallium arsenide is highly toxic, and insulating layers are also impossible to grow on it. And Josephson junctions currently must be cooled to near absolute zero to work. (Some theoreticians contend that Josephson junctions can be made to work at room temperature, but this so far has not been proven even theoretically.)

Still, if there is a place where quantum leaps in technology can already be sensed, it is in bubble technology. There was a time when storing information in the form of small magnetic domains in materials such as garnet appeared as dubious a prospect for commercial production and application as Josephson junctions appear today. But so great is the trust in the new magnetic-bubble technology that some semiconductor companies are producing quarter- and 1-megabit memories reliably and repeatedly, while 4-megabit and larger devices are near-term prospects. The leading applied scientists, indeed, brim over with enthusiasm.

"Bubbles will progress similarly to dynamic RAMs, quadrupling in density every 3 to 4 years, probably for the next 10 to 15 years," predicts Donald Bryson, formerly of Intel Magnetics Inc. in Santa Clara, Calif. And H. Dean Toombs, a vice president of Texas Instruments, observes: "My feeling is that there will be inventions along the way that will open the door to extremely high-density magnetic bubbles in very small chips. There will be some further fundamental invention or innovation in the area of structures and general technique that will provide a more viable approach than just pushing the presently known structures."

Today's quarter- and 1-megabit chips rely on coil-driven, field-access technology. That is, criss-crossed coils of wire carry an alternating current to provide a rotating magnetic field. Present chips and some future chips will also employ easily magnetized and demagne-

tized nickel-iron Permalloy shapes in the form of chevrons. These shapes take on the macroscopic field generated by the coils and become microscopic magnets with poles that rotate so as to be parallel with the coil field. The Permalloy patterns, located directly above the bubbles, attract the minute cylinders of reverse magnetization and pull them through their paces.

Although Permalloy patterns and field-access coils work well for 1-megabit chips, and although it is possible to exploit them for 4-megabit chips, performance and lithography requirements point to alternative technologies for future generations of bubble-device structures. Some real possibilities include:

- Contiguous disks. These ion-implanted patterns resemble minute overlapping pennies and can be realized in Permalloy. They have more relaxed minimum-feature lithographic requirements and need fewer masking steps than chevrons do. They also permit bubbles to move in either direction along a bubble-storage loop—an impossibility with chevrons.
- Current access. Instead of using field-access coils to move bubbles along their loops, scientists at Bell Laboratories have succeeded in moving them with one or more perforated sheets of conductive materials. Like the Permalloy, these layers are situated over the magnetic garnet where the bubbles reside. The obvious advantage is a simplified package due to the absence of coils. But this scheme can also mean +5-V-only operation, more easily automated testing and packaging, and faster operation because there is no coil inductance to set limits to bubble speed.
- Bubble lattices. Whether propagating structures are fashioned from Permalloy shapes or ion implantation, 1s and 0s are stored as the presence and absence of bubbles. However, bubble-lattice files, as they were named by scientists at the IBM Watson research center, store information in the form of wall states present on a single bubble. These states, infinite in number, are caused by twisting the magnetization along the cylindrical wall of the bubbles. Thus, one bubble can store both a 1 and a 0 (as the two lowest-energy wall states, typically), and higher density is an obvious byproduct.

Besides disks, current-access technology, and lattices, improvements in architecture will yield faster access times. That is, the number of loops and their position on the die will significantly improve performance. Also, chances are that improved garnets or completely new materials will be developed and used. And finally, because bubbles exist in very thin layers of magnetic material, the possibility exists that multiple layers can be built up to multiply storage capacity.

One major drawback with repeating patterns like chevrons is the thin gaps that must exist for the bubbles to transverse. Contiguous disks, on the other hand, can manage without gaps, and that is why their lithography requirements are relaxed. Coupling this with the fact that ion implantation could replace masking operations, a consensus has emerged that ion-implanted contiguous disk patterns will be used to construct the next generation of bubble memories. In fact, because of the processing simplification, and in order to become acquainted with the technology, some manufacturers will use disks in order to build 1-megabit and 4-megabit devices.

"Today's generation uses 3-μm bubbles," comments Cliff Cullum, director of applied research at IBM's Watson research center, adding that, "The next generation will reach the limits of optical lithography—1½ to 2 μm. After that will come contiguous disks." And from Bell Laboratories: "Think in terms of ion-implanted patterns, of which contiguous disks are just one possibility," says H. E. D. Scovil, director of its solid-state laboratory. "There's no question that ion-implanted propagation patterns will succeed," he says, but also warns that there might still remain areas on the chip for which multiple masks would still be necessary, "so the alignment factor could limit chip size even though most of the chip gets only a single mask."

Other schemes like current access and bubble lattices are at more elementary stages. "It is too early to conclude that conductor-access devices will become the technology of the next generation of bubble devices," states Andrew Bobeck, the Bell Laboratories scientist who has done much to improve the current-access scheme for bubble memories.

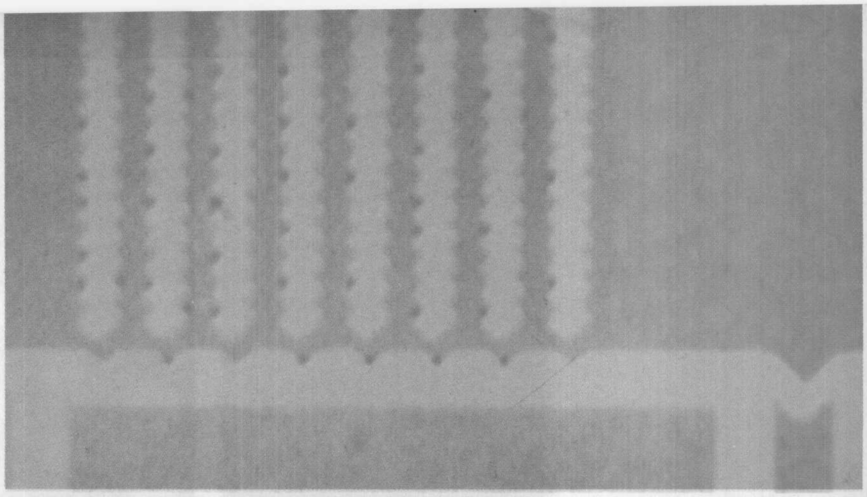
Nevertheless, writing in the July-August 1979 issue of the Bell Technical Journal, he goes on to summarize the benefits: "There are some features that only conductor-access devices possess. If high speed is a necessity, as in video-based systems, conductor circuits are the only option available to the device designer at present. The anticipated small package size will be significant in applications for which space is a premium. The ability to run with logic-level power supplies is another plus for conductor devices. Finally, conductor circuits will require fewer precision analog control circuits since the critical control function of rotating field timing has been eliminated." Bobeck is also of the opinion that it is possible "that the apertured sheet drive approach applied to the bubble-lattice file will make that structure more attractive."

TI's Toombs believes that the current-access idea "does have the potential of operating at megahertz kind of propagation frequencies." And it comes about, obviously, because the coils have been eliminated. Although current access is "attractive and has potential," the approach poses materials problems, he says. "You have to produce garnet films with lower dynamic coercivities." This means that the garnet must be more easily magnetized and demagnetized, because the fields produced from the conducting sheets are less than those available from coils. "You've got to produce a garnet film where you can move bubbles with relative ease," says Toombs, and "that's a function of coercivity."

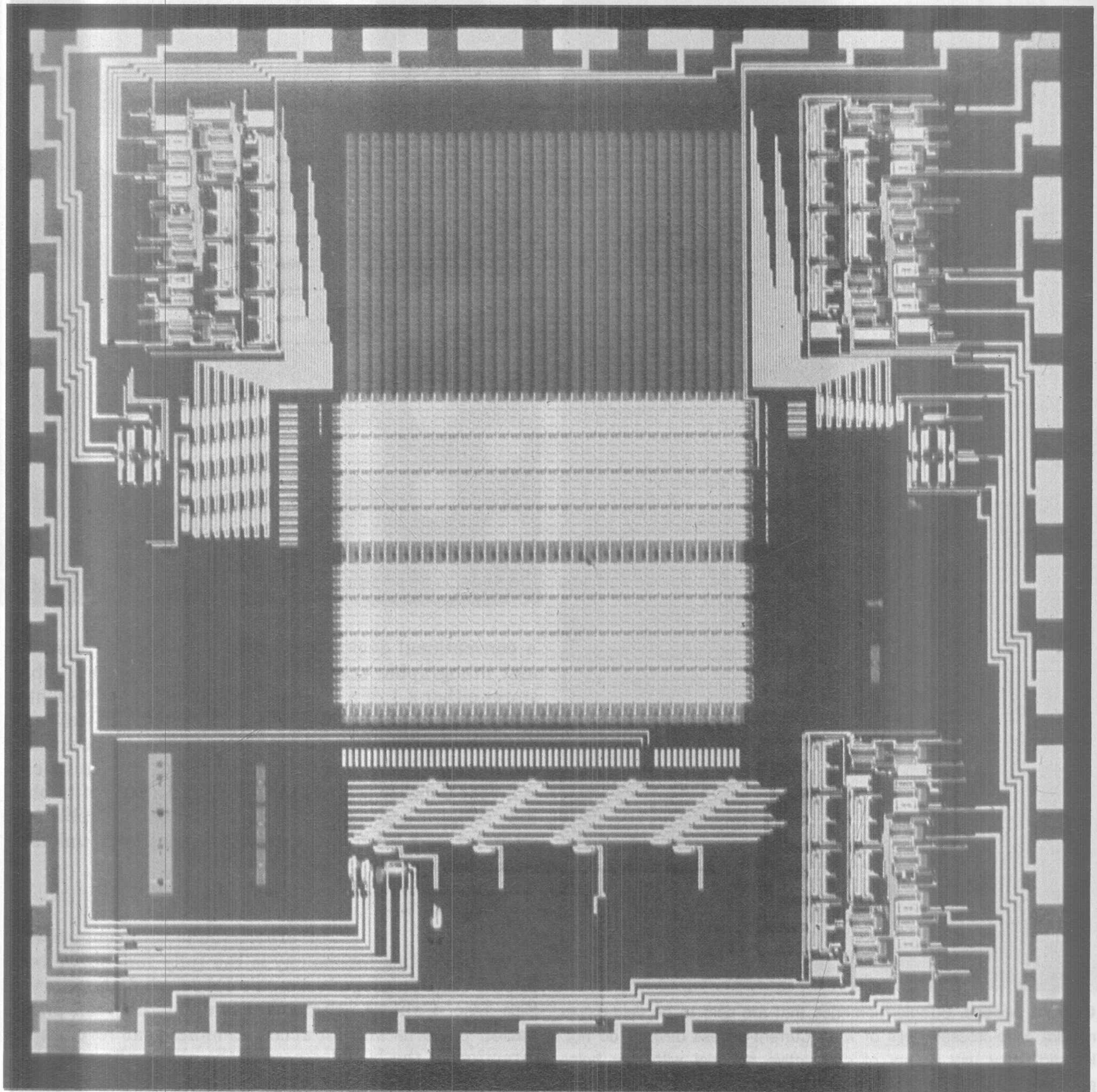
However, the benefits of the current-access approach seem to outweigh the drawbacks, so the idea will undoubtedly be pursued in future bubble chips. Another possibility with the current-access approach is three-dimensional storage: because the field used for movement is very local with regard to the garnet supporting the bubbles, multiple layers of garnet (or some other highly coercive material), metal, and insulator could conceivably be sandwiched for incredible storage.

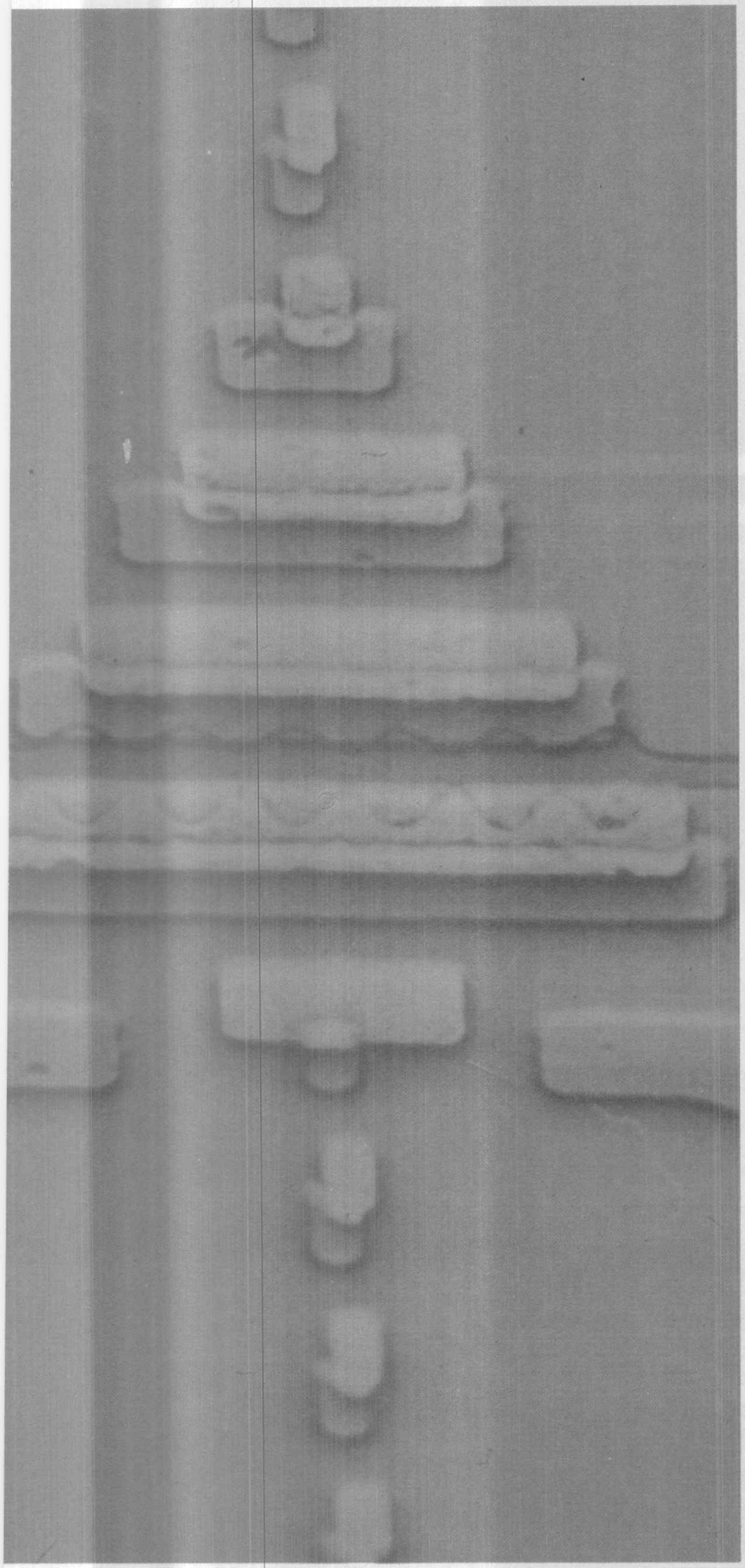
Bubble lattices offer quadruple the storage density of

structures and bubble lattices are put to use, contiguous disks will be. Although they can be made from Permalloy, the best approach is to ion-implant them. They have no gaps, so more bubbles can be stored.

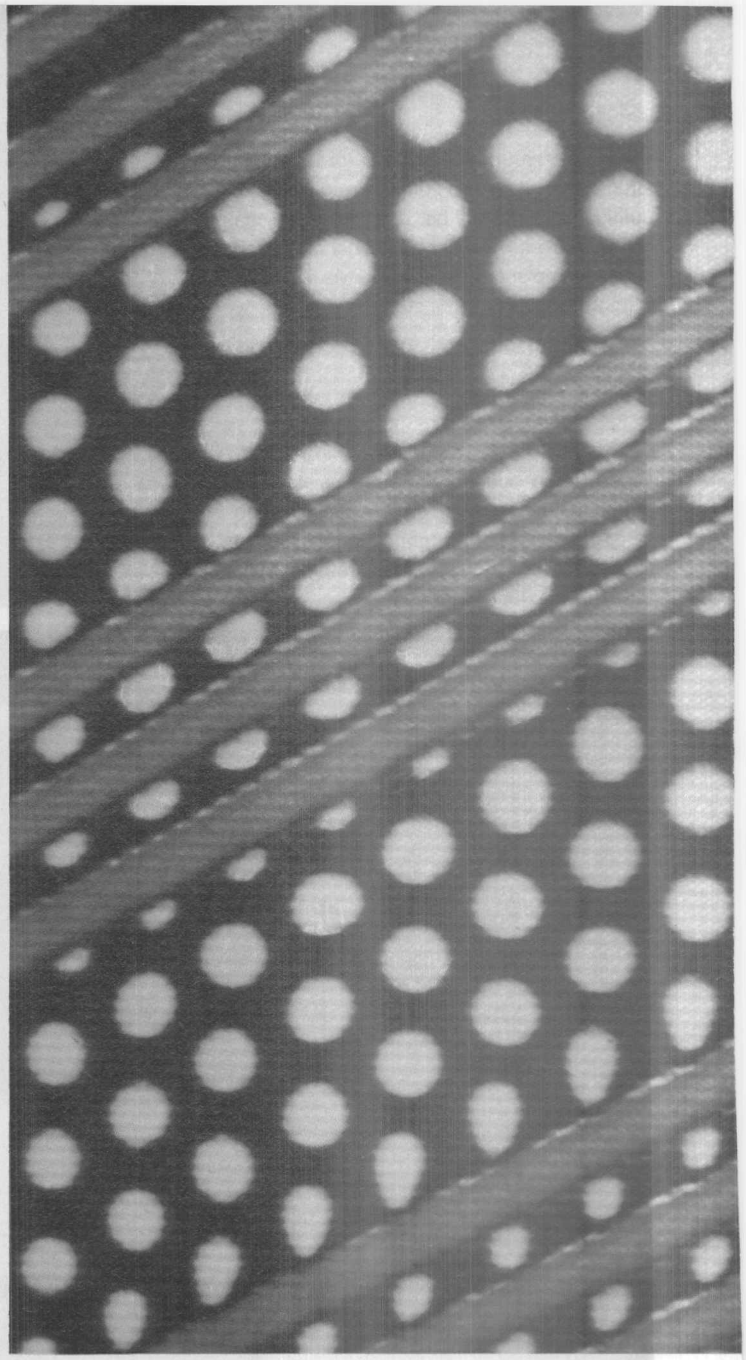


Josephson. For the ultimate in speed, super-cooled Josephson junctions can be turned to. These can be switched in less than 10 picoseconds, but fabrication is critical and operation requires temperatures near 0 K. The chip below is a memory.



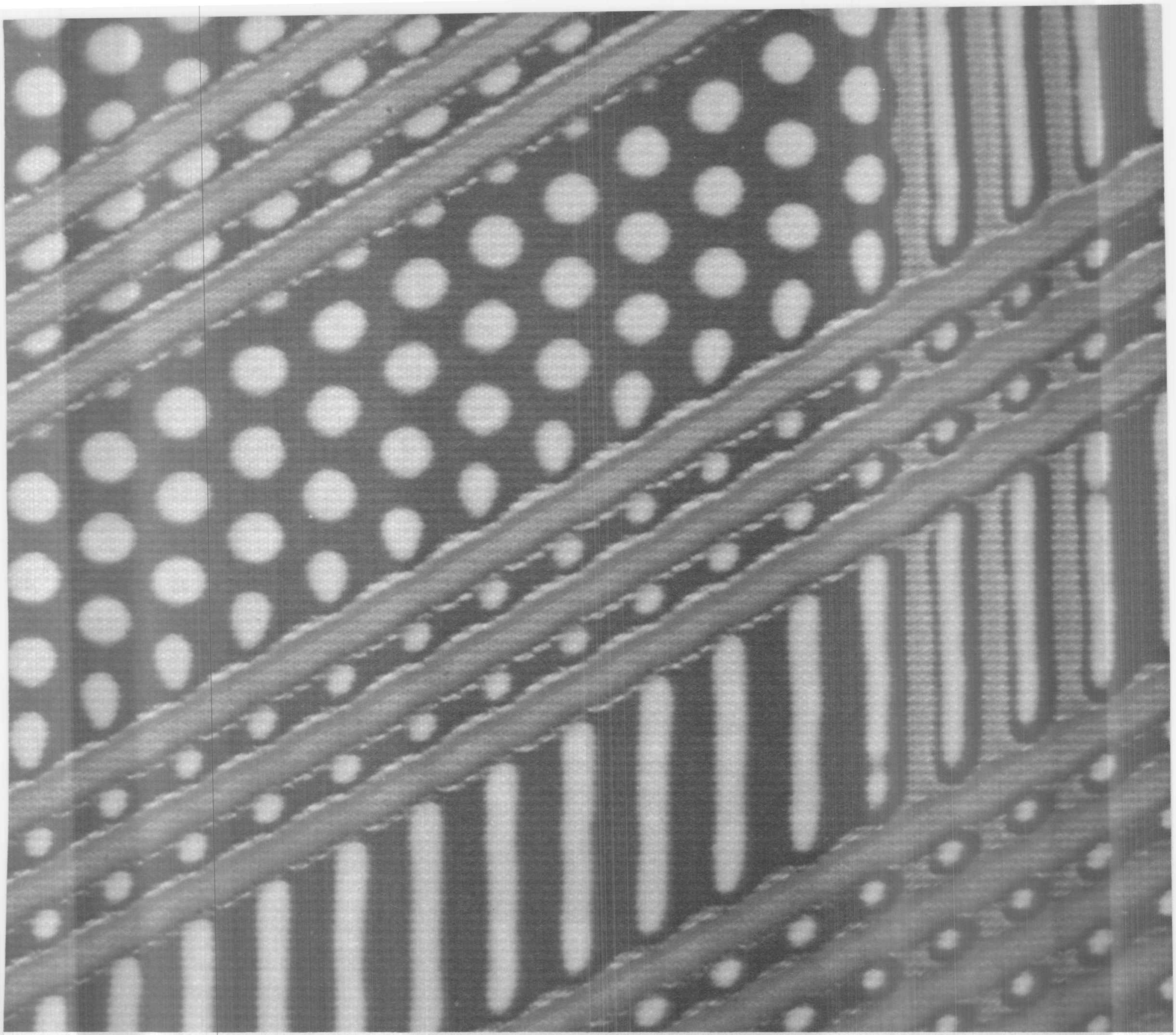


Current access. Bubble memories that are said to be field-driven require criss-crossed coils of wire. Current-access devices do not. Instead, they use sheets of conductive material with tiny holes punched in them. At the holes, fields are created that move bubbles.



a conventional device having the same bubble diameter and lithographic resolution. But because every bubble stores either a 1 or a 0, there must be a bubble present at every site in the array. This is a benefit as well as a difficult engineering problem. It is a blessing because of the increase in information packing. But bubble spacing is a very delicate matter: too close, and a pair of bubbles may collapse and merge; too far apart, and a bubble may strip out and form two distinct bubbles with unknown wall states.

Perhaps the most recent advance in bubble-lattice technology is the fully functional 14.5-kilobit chip developed at IBM's Research Laboratory in San Jose, Calif. Asymmetric Permalloy chevron propagation patterns and an access channel that reverses the direction of the bubbles permit the chip to be organized into major and minor loops. However, large-capacity



Lattices. This enlarged bubble-lattice device is a piece of art. The bubble lattice can store more information because a bubble is present at every position and 1s and 0s are stored as bubble-wall contortions and not as the presence or absence of a bubble.

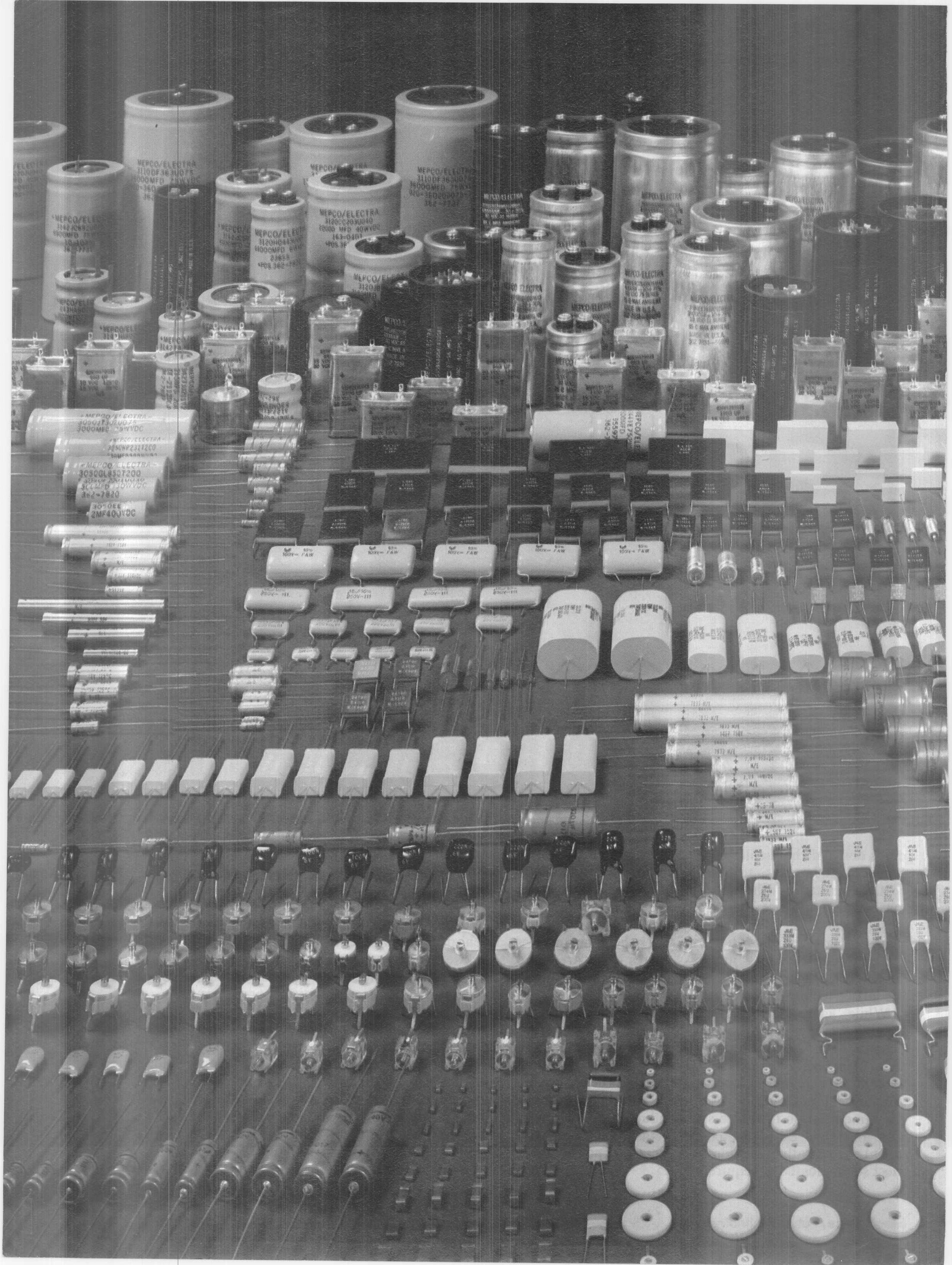
chips demand that some loops be allowed to be nonfunctional or redundant, to increase chip yield and lower cost. In structures other than lattices, such loops can be masked out and not used, but in lattices they are too closely packed for this to be easy. One solution is to have banks of lattices separated by areas where no bubbles are allowed to exist. But this wastes chip area and subtracts from the extra capacity gained by switching to the lattice technology.

While garnet already is outperforming silicon in providing ever greater memory densities, other materials promise also to outdo it by at least an order of magnitude in speed. Among the III-V compounds, gallium arsenide in particular comes to mind, and then there are Josephson junctions, too. As noted, silicon bears much the same relation to future semiconductor technology as iron and steel bear to modern metallurgy: immensely useful structurally and widespread, but just not up to the most sophisticated of requirements.

Nor is a change from silicon so very radical. Richard Eden, principal scientist for solid-state electronics at the Rockwell International Science Center in Thousand Oaks, Calif., calls it no more drastic than growing silicon on sapphire to reduce parasitic capacitances.

The basic circuit element made with GaAs is the metal-semiconductor field-effect transistor (MES FET). The device is very simple; it consists of a thin low-resistivity layer deposited on a high-resistivity substrate with a Schottky diode gate between two metal source and drain contacts. It operates just like a junction FET or JFET: the voltage on the gate determines the width of the depletion layer, so the voltage on the gate controls the current between the source and drain.

It is possible to make MES FETs in silicon, but silicon's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lower mobility means there is less of an incentive to do so. Conversely, since insulating layers (like SiO_2) can be grown on silicon but cannot, at present, be grown on GaAs, GaAs MOS FETs have not yet been fabricated. But JFETs, heterojunction FETs (HJFETs), charge-coupled devices (CCDs), and transferred-electron devices (TEDs) have been made on GaAs. In addition, both enhancement-mode and depletion-mode MES FETs have been obtained with the material.

It is generally agreed, therefore, that gallium arsenide will find its way into integrated circuitry, but when and to what extent is argued. "I'd be surprised if we don't have useful gallium arsenide ICs," says Bell Labs' Fletcher. "But it's not likely to replace silicon in the near future. The higher speed is accompanied by a lower level of integration." "We currently have gallium arsenide devices at frequencies up to about 20 gigahertz," says Michel Carpentier of France's Thomson CSF. "That's just a beginning. It took about 25 years to obtain control over silicon, so there's another 15 to 20 years ahead for GaAs. And indium phosphide will follow. We're not at all squeezed for getting to much higher frequencies."

The last comment, about not being squeezed for higher-frequency performance, is the same reason why another technology—potentially the fastest—has not enjoyed more success. That is the Josephson junction, created by the British physicist Brian Josephson who later shared a Nobel prize for the work. Much of the current investigation is being done at IBM's Watson research center, and so far, the devices still need to be cooled to temperatures near 0 K.

IBM's Cullum summarizes the challenges with Josephson-junction technology:

- Materials. Josephson junctions are made with lead alloys—not silicon. A pure lead junction is destroyed after being cycled only once. Hence, the development of suitable lead alloys was a big step along the road to the practical devices of the present, which have undergone hundreds of cycles in the laboratory.
- Processing. The junction itself—the barrier between two superconductors—has to be on the order of 50 Å with a few percent tolerance. The properties of the device depend exponentially upon this barrier thickness.
- Packaging. The ultimate switching speed for a Josephson junction is around 1 picosecond. At present, too much delay is introduced in going from one circuit to the next and into and out of the device. Thus, Josephson devices must be very small and incorporate entire subsystems to be effective.

The latest Josephson circuit from IBM uses current-injection logic. The circuits operate in as little as 13 ps, but while the actual switching time is 7 ps, it takes another 6 ps to get to the next circuit. AND and OR gates have been constructed.

Recall that Gordon Moore confessed to having little idea how to take advantage of VLSI beyond memory products and that the real problem was how best to use the results of the processing technology. Certainly, in the near term there will undoubtedly be a spillover—as there has been in the past—between memory technology and processor technology.

And it is safe to predict certain other developments, too, like improved ways of interfacing microcomputer-based systems to real-world variables. Advances in the making of integrated circuits have for too long outdistanced the progress made in sensors and converters, and both will have to make major efforts to catch up.

For instance, two of the transducer's traditional problems—linearity and stability—are no longer serious impediments to its progress, thanks ironically enough to the microprocessor. By statistically processing unstable signals and linearizing them, the microprocessor could make good the transducer's performance, so future sensors are expected to contain microcomputer chips within the same package. And since the microcomputer is already a low-cost item, inexpensive sensors making use of its computational capability can thus be expected to proliferate widely.

As for the analog-to-digital and digital-to-analog conversion devices, current advances in monolithic converter technology can be expected to yield complete a-d and d-a converters with as much as 16 bits of accuracy, within a single chip. Indeed, complete one-chip 8- and 10-bit a-d and d-a converters are already here, and future high-accuracy high-resolution converters are expected to share the same chip as the microprocessor.

Electro-optic devices, too, will play larger roles. Liquid-crystal materials will be perfected to the point where liquid-crystal panels will display multiple lines of dozens of alphanumeric characters at low cost. As for high levels of information display, the familiar cathode-ray tube will likely give way to larger and thinner gas-discharge panels capable of displaying hundreds of alphanumeric characters in color, with near-infinite resolution, at low cost. A leading future contender for computer-output information display is the electrochromic display, which has excellent contrast levels, is aesthetically pleasing, can operate from very low voltages (about 1 to 2 V), and dissipates little power. One possibility is to employ an optical beam to address the electrochromic material in the display for large-screen graphics as well as for alphanumeric information display.

Charge-coupled devices will also do well as infrared imaging and sensing devices. CCD arrays capable of acting as television cameras have already been put to use as industrial surveillance and inspection systems. Focal-plane CCD arrays, with infrared detectors, preamplifiers, and multiplexing circuitry on the same chip, will become a reality. So will monolithic CCD arrays that have both imaging functions and digital signal-processing functions in the same package.

Since CCD arrays can read in data at very high speeds and write it out at much lower rates, they will be ideal as low-cost signal-processing elements for transducers. Typically, CCD arrays operating with input data rates of hundreds of kilohertz per second—orders of magnitude reductions in input/output data rates—will become common and widely used.

Meanwhile, the expanding communications market

Fujitsu's Bubble Memory Cassette

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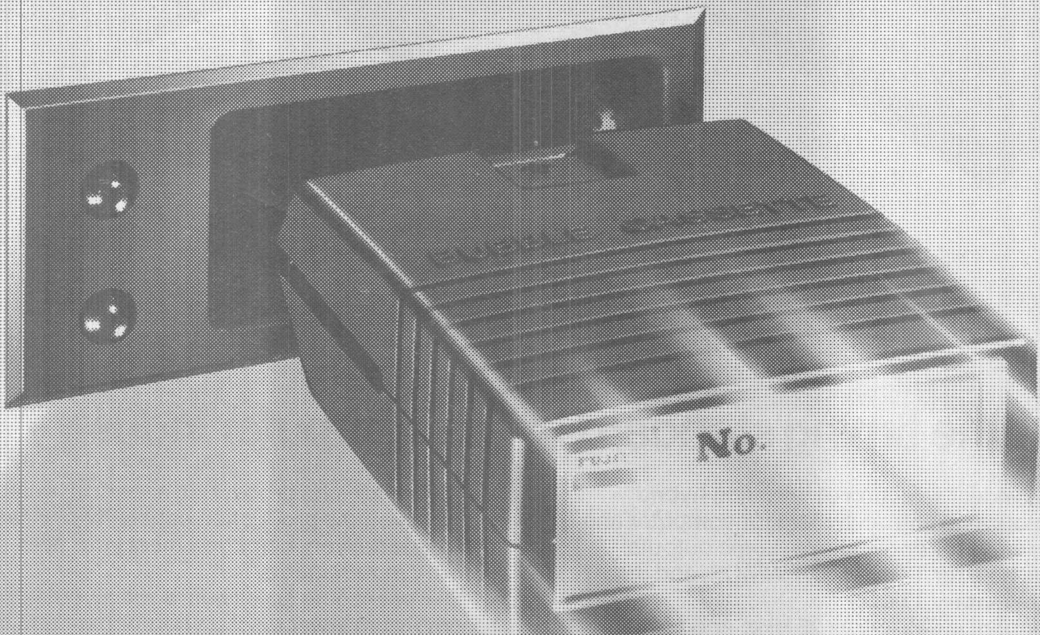

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typical integrated optical IC will contain the light source, modulator, carrier, and detector on the same thin-film chip and will transmit data over fiber-optic cable much faster and more efficiently than now possible. Improvements in the reliability of aluminum gallium arsenide light sources and lifetimes on the order of 40,000 hours will make them the primary candidates for long-distance optical telecommunications in the 0.8-to-0.9-micrometer-wavelength region. Still other integrated optical elements will play a role in data processing, where they can be expected to perform signal transforms, correlation functions, and so on at exceptionally high speeds, for real-time applications.

But the influence of VLSI will undoubtedly be centripetal as well as centrifugal.

"The major impact of VLSI will be on computer architectures. It will affect everyone: mainframe, minicomputer, and microcomputer manufacturers," says Intel's Vadasz. "As microcomputers perform higher and higher levels of functions, the burden is more and more in the cost of the software. Consequently, more and more of the architectural solutions will put the software burden onto silicon. That has to be the major impact of VLSI."

One of the changes in store for microprocessors and single-chip microcomputers—the dramatic increase in on-chip memory capacity—will erase the distinction between the two devices. Every microprocessor will be a microcomputer.

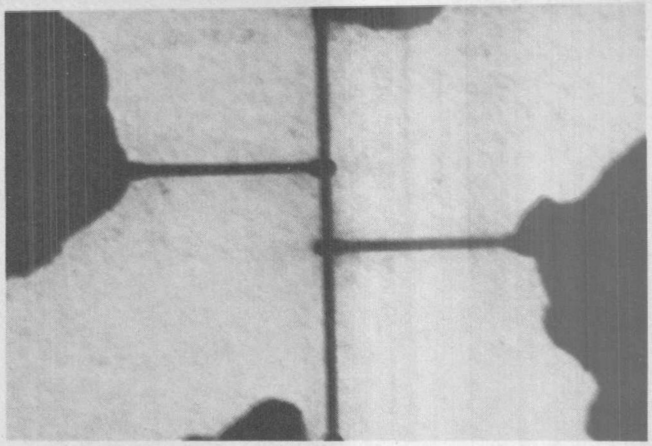
Specialized processors will become more common. They will be designed expressly for data-base management, high-level language execution, distributed processing, and so on. Evidence for such processors can be seen today in the devices built for floating-point mathematics and input and output. However, marketing these processors will require ingenuity because, being customized for a task, they will not enjoy the volume markets of general-purpose chips.

Processor elements will become more regular architecturally and will therefore make increased use of microcoded control sections and programmable logic arrays. The use of nonrandom circuitry will be the only way to manufacture the chips economically. And when the devices have become completely modularized, the customer will be able to pick and choose functions.

Input and output will become much more intelligent and comprehensive on the microprocessor chip itself. This will be especially true for serial communications, whose protocols and high-level data-link control will be incorporated on chip. Such comprehensive high-speed serial control will help to alleviate the packing problem that is inevitably in store for processing elements.

Finally, on-chip diagnostic features will play a key role in future processors. The complexity of future processors will otherwise present their users with formidable testing difficulties.

Of course, the word width of future processors will grow. But many feel that it will be a long time before 32 bits is exceeded. TI's Heilmeier says that "as a rule of



Even more slender. An experimental Josephson nanobridge developed by IBM switches without a junction. The lines in the circuit have widths and thicknesses of only 100 to 200 atomic diameters (30 to 40 nanometers). Electron beams exposed them.

thumb, the required word length of a processor goes up by 1 bit every two years." Thus, 32-bit devices will carry the industry through the 1980s, at least. He says that wider words are justified because the problems of each generation need more memory to solve them. One concept in particular that will catch on is machine intelligence, he says, and it will demand wide-word microprocessors. By his definition, an intelligent machine is characterized by qualitative rather than quantitative computation—that is, it is capable of inference and deduction and of answering questions asking how and why certain results occur. "I hesitate to say what comes beyond 32 bits for microprocessors," he adds, "because there are other things to put on the chip."

One of those things is analog input and output. The most efficient way to do this may require the mixing of technologies on the chip, with bipolar around the periphery of the chip to interface with the outside world, MOS on the inside for dense logic. "The microcomputers will go closer to the analog signals that the real world has," says Zilog's Faggin.

And of course, it is this real world of human beings that will in the end determine the path of development of the data-processing revolution that is this generation's gift to posterity. There is no single answer to Gordon Moore's question about how best to use its results, because the answer, of course, depends upon a variety of factors. Not the least of these is how much consumers will be willing to pay for increments in convenience and power that will result from computerizing increasingly large sectors of daily life.

It is clear that daily life will be affected in a myriad ways. The pervasiveness of the image of the robot in mankind's technical imagination guarantees the continued search for the machine that will be the perfect slave. And the guts of such a machine will be the logic devices and memories foreshadowed in the work being done experimentally today. But its impact on society will depend upon where society is going. The dynamics of development that have carried computers thus far are rooted in the competitive nature of an industrial age. □

$$\frac{C(z)}{r(z)} = \frac{G(z)}{1+G(z)}$$

ENGINEERS

50 YEARS

ADVANCES IN ELECTRONIC TECHNOLOGY WILL REDEFINE THE ENGINEER'S JOB. CLEARLY THE DOMINANCE OF DIGITAL SOLID-STATE TECHNOLOGY DURING THE NEXT TWO DECADES WILL MAKE IT THE MAINSTREAM OF ENGINEERING ACTIVITY. OF GROWING IMPORTANCE WILL BE CAREERS IN SOFTWARE DEVELOPMENT. KNOW-HOW IN COMPUTERS AND COMMUNICATIONS WILL ALSO BE PRIZED. MEANWHILE, NEW TOOLS LIKE HIGHLY SOPHISTICATED COMPUTER-AIDED DESIGN PROGRAMS AND EASILY ACCESSED DATA BASES WILL EVOLVE ALONGSIDE NEW FORMS OF TRAINING. CURIOSITY AND CREATIVITY WILL STILL THRIVE, BUT IN A GREATLY CHANGED ENVIRONMENT.

... electronics engineers in the year 2000 are just now learning to walk and talk. As they grow up, the profession they will be entering will be growing, too. So when they begin their first jobs, many aspects of what they do, where they do it, and how they will do it will be different from the daily work life of today's EEs.

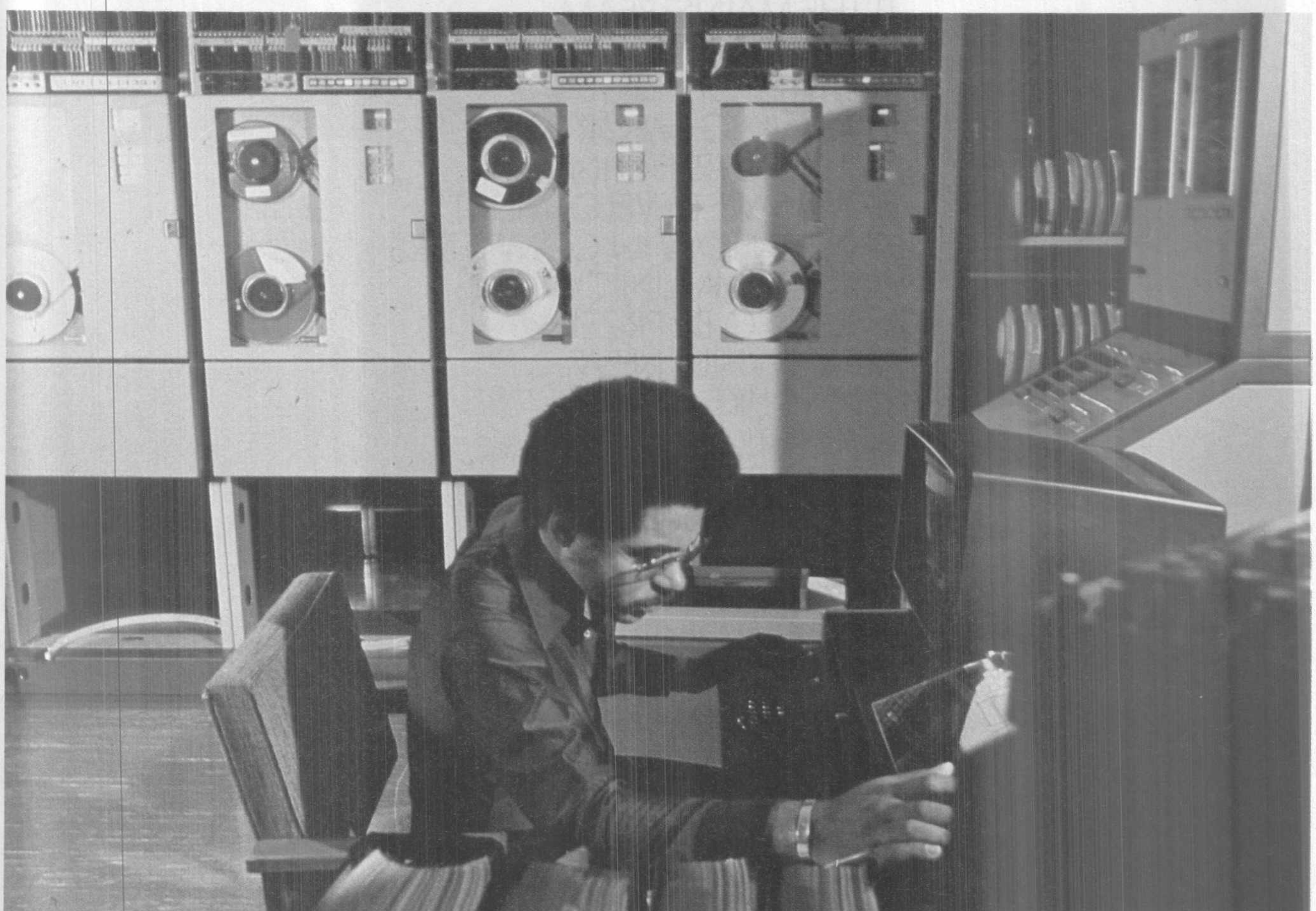
Conversations with working engineers, engineering managers, electronics executives, and educators disclose broad general agreement on what the changes will be and on what is likely to remain unchanged. Of course, there are some caveats everyone recognizes: the dynamism of the profession will introduce complexities that cannot be predicted; the pace of innovation will be uneven from industry to industry, even from one job type to another; and there is no way of anticipating revolutions in technology.

One point of general agreement: the triad of semiconductors, digital logic, and circuit integration will be the dominant technology until the end of the century and so will offer the key job opportunities. Systems design and software development are going to be hot areas, and new opportunities will arise in energy-related areas in particular. Such developments may not call for a new breed of engineer, but certainly new qualifications will be needed: among them, the ability to develop in-depth specialties, more keenly developed sense of the relationship between the work and the rest of the world.

The engineer's workplace and the tools that he or she uses are likely to undergo some radical changes—although these are areas where varying rates of change are likely to be most noticeable. And what will be obvious immediately will be the much stronger representation of women and members of minority races. This will be brought about both by the increasing perception of the desirability of electrical engineering as a career and by the realization of EEs' employers that these groups contain vast numbers of potential recruits to fill the probably chronic shortfall of engineering talent.

With all the changes, the educational system is likely to look rather different in 20 years. Still, the same basic teaching method of interaction between the instructor and student is likely to prevail, even with the growth of methods such as computer-aided instruction.

As the sliding scale of integration moves to the million-device chip and beyond, the lives of designers of integrated circuits and of the products using the ICs will change inevitably. It is already widely recognized that the super chips will present staggering problems of design, and that computer-



Automated workplace. By the year 2000, most electronics engineers will be using computers in their work. At Bell Laboratories' various locations today, there already is one computer terminal, complete with printer or cathode-ray-tube display, for every two employees.

Designers needed. Despite the inevitable growth of highly sophisticated and versatile computer-aided design systems, human designers of very large-scale integrated circuits will still be playing an important role, says L. J. Sevin, the chairman of Mostek Corp.

aided design is likely to rise to the challenge. "The engineer will need all of a computer's resources to handle increasing levels of complexity, with the prospect of encapsulating up to 10 million logic gates on a chip," notes William Gosling, professor of electrical engineering at Bath University, England.

Still, the development of highly sophisticated and versatile CAD systems does not mean that the computer will take over design. "We're always going to need people to come up with the architecture," says L. J. Sevin, board chairman and chief executive officer at Mostek Corp., Carrollton, Texas. "We're even going to need people who do something very like the circuit design that's being done today."

Sevin also believes that CAD will cut the number of jobs available in circuit design—a view not held by some other forecasters of the future. For example, Paul C. Ely Jr., vice president and general manager of Hewlett-Packard Co.'s Computer Group in Palo Alto, Calif., anticipates an increasing need for designers of large-scale ICs, "more so than we need people to work on the processes themselves," although he expects "a relatively small number of people will actually design million-element circuits."

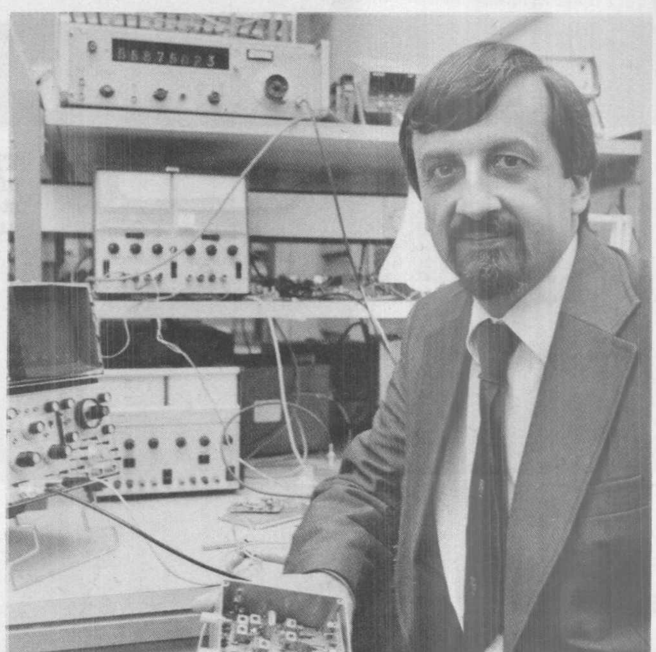
"I don't think circuit designers are going to go away," agrees Stephen A. Szygenda, assistant chairman of the EE department at the University of Texas, Austin. "The job is becoming more complex, so it's reasonable to assume that it's going to evolve into a number of jobs. But the basic building elements are still going to be circuits, and circuit designers are going to be needed to design them." Szygenda, who also runs a computing systems consulting service, adds that exploding demand, too, will be a big factor. Computer-aided design will not result in fewer jobs, he says. "The only thing CAD does is to provide a repertoire of tools for doing things that we can't do cost-effectively without them."

Of course, LSI has moved chips out of the components category, and very large-scale integration and beyond will move them into the subsystem category. For designers of end products, then, the locus of their work will be on the systems level. Designing at this building-block level may not require the kind of detailed knowledge of circuitry required today. "It won't be important for the average EE to have an intimate knowledge of central processing units, unless he designs CPUs," says Jim Lally, general manager for development systems operations at Intel Corp., Santa Clara, Calif. "It will be important to know how to get the functional building blocks of a system to talk to each other."

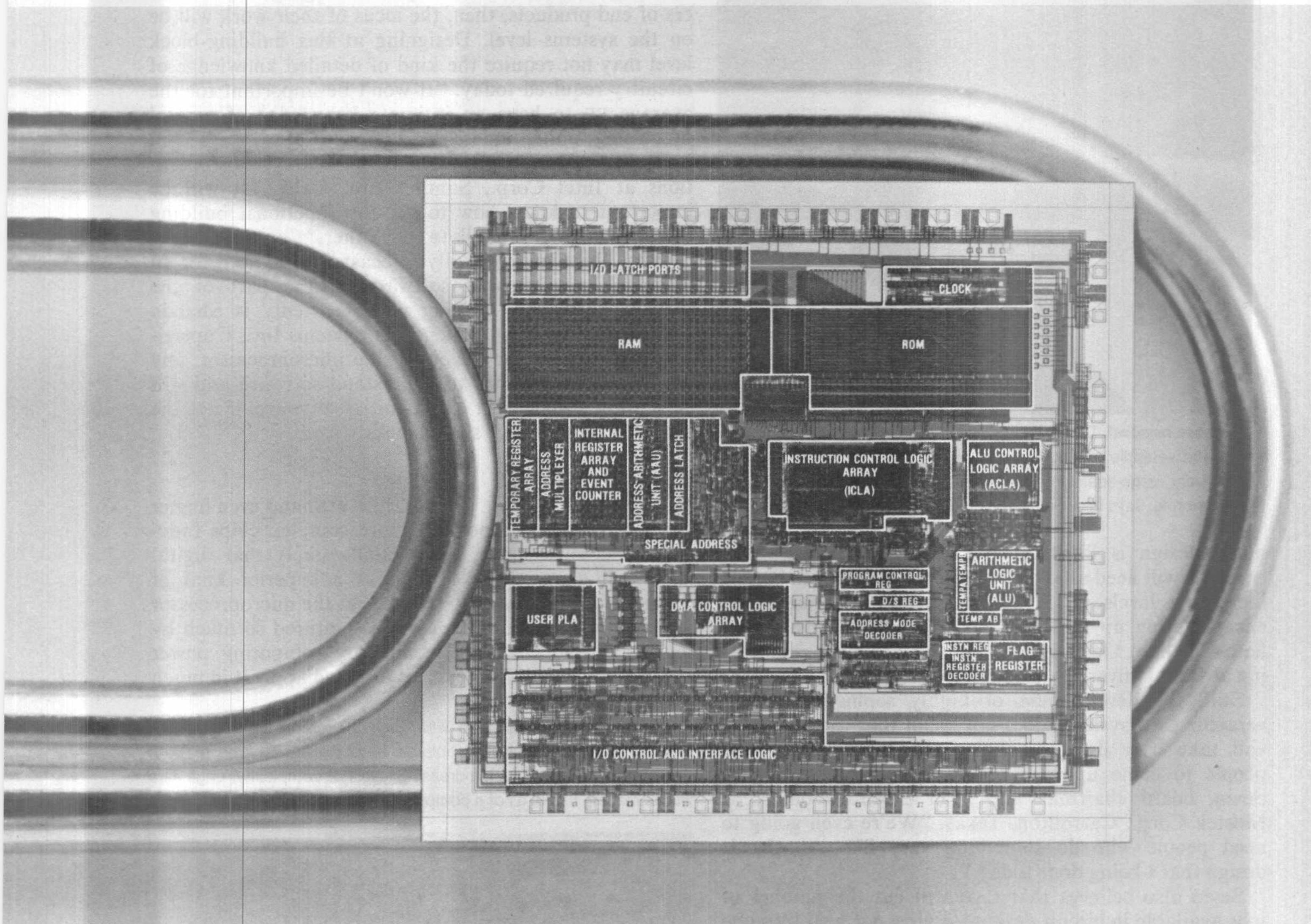
What this signifies, Lally forecasts, is the need for an intimate knowledge of software on the part of the systems designer. Agreeing wholeheartedly is Shanda Bahles, a designer at Millennium Systems Inc., Cupertino, Calif. "With the advent of the microprocessor, any hardware designer has to understand software and will be writing a good part of the initial software, if not the production software," she remarks.

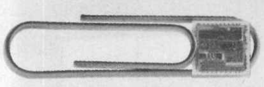
While VLSI and even higher levels of integration portend more complex chips functioning as subsystems, it is equally likely that digital logic will come to be treated as a superior kind of component. "It may very well be that the microprocessor segment of the industry may have matured so much by the year 1990 that you would buy computing power much as you would buy capacitance and apply it in much

Super problems. VLSI chip with, say, 10 million logic gates will present formidable design problems, says William Gosling of Bath University. To handle such increasing levels of complexity, engineers will be making use of all of a computer's resources, he says.

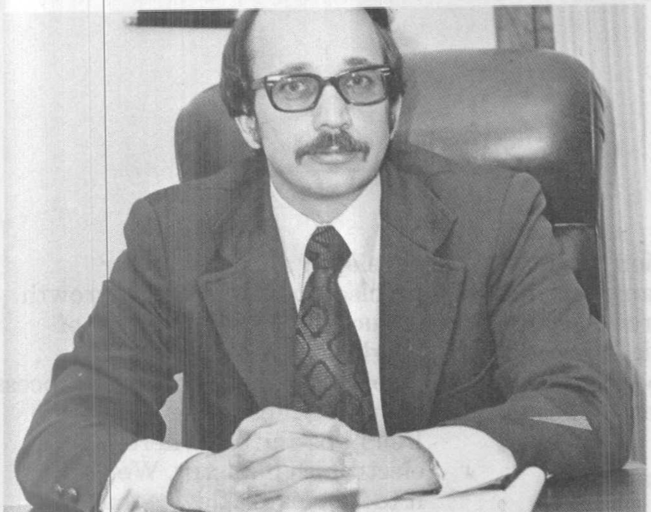


The one-chip computer: offspring of the transistor





The MAC-4 one-chip computer, developed for a variety of telecommunications applications, is compared to a standard-sized paper clip. The chip's numerous functional areas are labeled.



Coding's cost. Already software development is expensive, but the costs are likely to become even greater, says Steven A. Szygenda of the University of Texas. The reason is evident: complex chips will require complex test programs to exercise them fully.

Disciplines melding. Watch for a growing need for systems designers to understand software, says Shanda Bahles of Millennium Systems Inc. Moreover, programmers will need to know more about hardware design in order to write effective software, she says.

the same way—that is to say, using a known and very clear-cut set of ground rules," predicts C. Gordon Bell, vice president for engineering at Digital Equipment Corp., Maynard, Mass. Thus end-product design need not entail sophisticated knowledge of electronics, and indeed, as applications spread into yet untouched fields, designers may well not be EEs at all, he forecasts. In such fields, "EEs will work in the interfacing domain: they'll work on problems of getting information into and out of computers, even though computers will be quite small in the perspective of large systems," Bell says.

Another aspect of the computer or subsystem as a component will be the dramatic improvements in efficiency that it will bring to the design task, almost across the board. The change is already beginning to appear in the design shops of state-of-the-art companies. "A good illustration that strikes home with me as the general manager of an operating design systems group is that the productivity of a product design engineer has increased five times in the last few years," says Intel's Lally. "Before, designing a floating-point processor to increase the capability of a computer substantially would take five design engineers along with three product engineers, two draftsmen, and four technicians 12 to 15 months to come up with three to four boards loaded with TTL. Now you can buy one chip that will do 90% of the job." Such advances not only make the life of the engineer easier, but they also will offer a partial answer to the shortage of design talent that shows no signs of abating.

Already industry savants are aware that programming the systems of the future will be a tremendous task. As the University of Texas's Szygenda points out, cost is a major factor; for a considerable time now the expense of software design has outstripped that of the hardware design. (A not incidental reason, of course, is the rapidly dwindling cost of the hardware.) The highly complex chips that will offer vast new capabilities will undoubtedly require highly complex new programs to put them through their paces.

Certainly software development will benefit from improved tools that will increase productivity. Still, there will be plenty of work for the engineer interested in programming as a career. The explosion in applications is another factor insuring the growth of the field.

The widening range of applications will mean that programmers will increasingly need an understanding of hardware as well as of software, says Roger R. Bate, manager of the advanced software technology department in Texas Instruments Inc.'s Equipment Group, Lewisville, Texas. He cites the TI experience with large military software projects. Often these programs must be designed with an eye towards interaction with various sensors and the like. Thus the software developer must work much more closely with the hardware than when he simply programs large machines with sophisticated operating systems.

Bate foresees a problem looming: "The explosive growth in the application of computers will require an increasing number of people who can make those applications work." Unfortunately the demand will outrun the supply of qualified programmers, and this shortage will begin to limit the application of computers within about five years, he feels.

A strong dissent comes from Mostek's Sevin, who argues that, in the VLSI era, programming requirements will ease as software packages for dedicated processors head toward standardization. Also, languages will be block-oriented and very simple, so that secretaries and other nontechnical personnel will be able to do their own applications programs, he says. However, for the fewer

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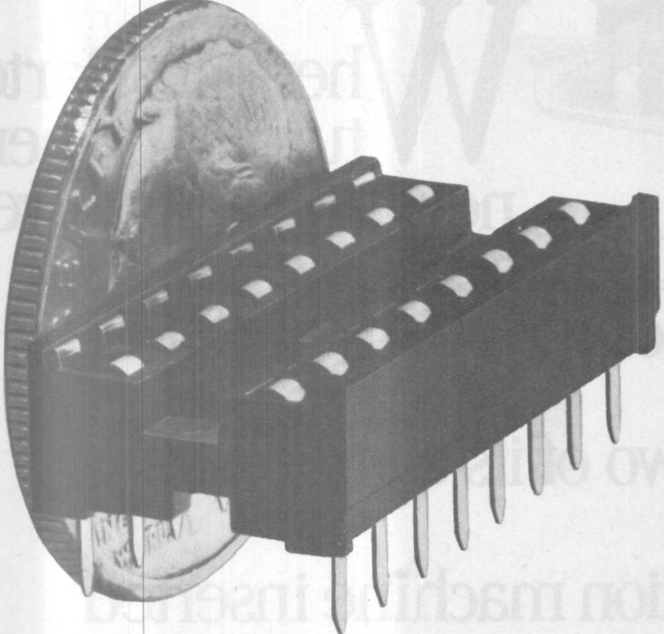

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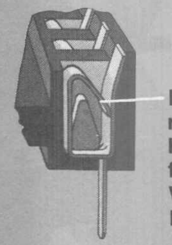

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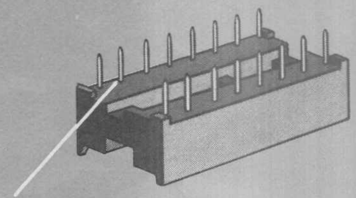
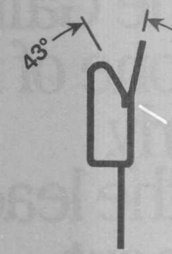


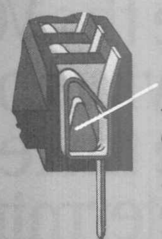
Top loaded contact. Press-fit into socket housing prevents solder wicking.

WIDE TARGET AREA



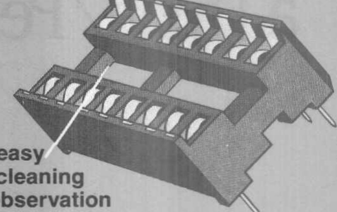
Dual-sided contacts, ramped in. Handles splayed leads or off-center insertion.

ANTI-OVERSTRESS BARRIER



Protects contact from overzealous probing or clumsy insertion.

OPEN FRAME CONSTRUCTION



Allows for easy P.C. board cleaning and trace observation or repair.

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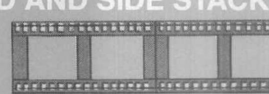
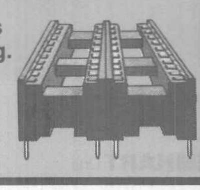


On .100″ centers. Provides for high density packaging. Also machine insertable.



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programming jobs available, "the sophistication and technical requirements will increase without bounds."

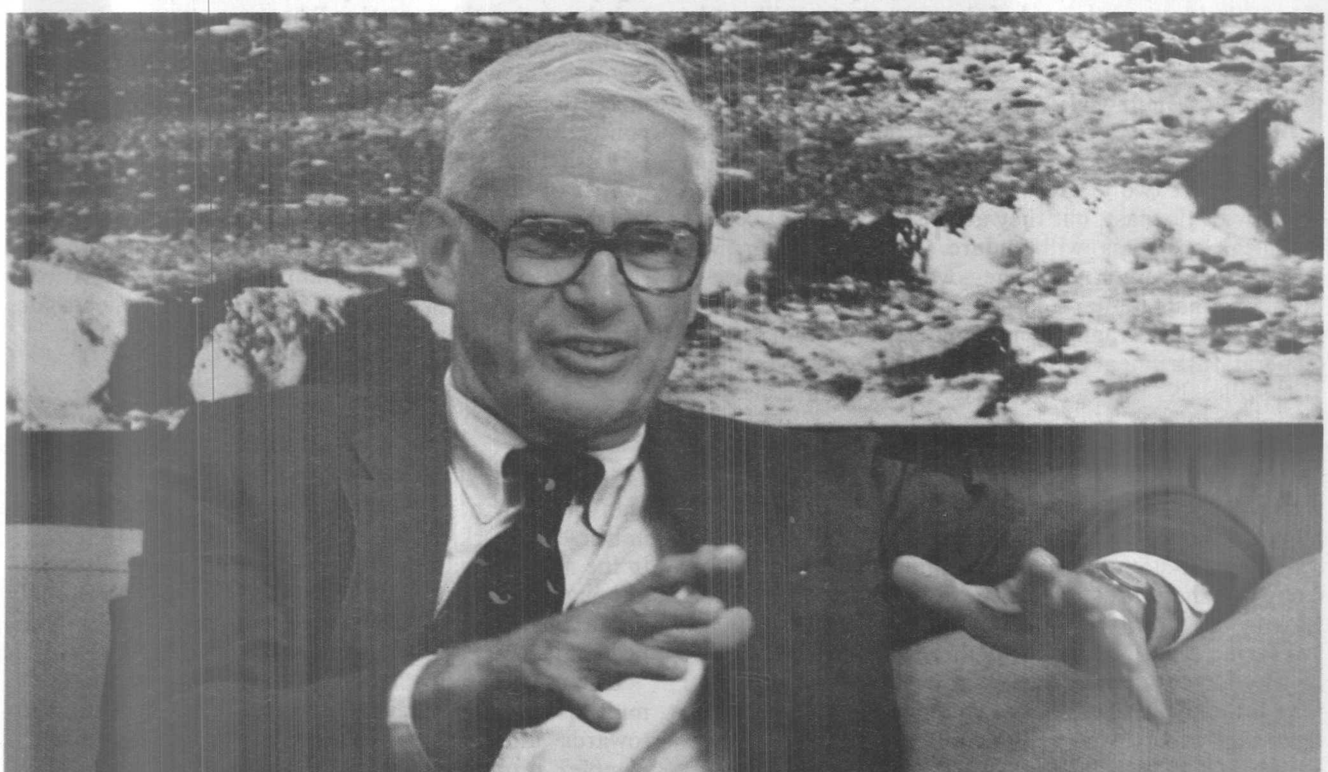
Sevin's position may be a minority one (and a minority of one, albeit from a man with a good track record on charting the future). Among the prognosticators in the majority camp, discussion is already under way on ways to meet the forthcoming shortage. Bate, for example, foresees the appearance of the software technician to relieve program writers of many tedious routing tasks. Typically, he says, the graduate software engineer will do the design and definition work, then turn the project over to the technician for the actual program writing. "The technician will play an especially important role in software testing and maintenance," he notes.

The software technician's job, for example, is one that will grow almost organically from the present organization of work in the electronics industries, but many other new job categories will appear in the next 20 years. The opportunities will be in the applications of electronic technology. Such use can already be seen in medicine, where the electronics revolution is only starting, and in the home and the office that will be the major beneficiaries as the post-industrial society moves into the Information Age. Moreover, it may be, as Gordon Bell suggests, that many applications will take plug-in computing power, so they will not require an EE's expertise.

One vast applications area, which overlaps almost all others, should predominate in the next 20 years: energy. It is hardly necessary to point out why the swift, sure control of digital logic will play so vital a role in solving the energy crisis that is gripping the world. For example, look for "a resurgence of the power side of electrical engineering" that will intimately involve the practitioners of advanced electronics, asserts Robert C. Seamans Jr., dean of engineering at the Massachusetts Institute of Technology. Just a few of the technologies subject to intensive research are magneto-hydrodynamics, cryogenically cooled power generation, and fusion energy, he says. There will be many opportunities for EEs because the complexities of the technical problems involved may be amenable only to electronic solutions. A case in point is nuclear power, Seamans says, where the Three Mile Island crisis laid bare the need for vastly more intelligent instrumentation and for better training in crisis management, inevitably involving better electronic simulators.

Moreover, power electronics will be only the tip of the iceberg, as illustrated by the work on environmental management in building and on pollution and fuel controls in automobiles. The synergistic nature of solutions to the energy crisis may be glimpsed in the mushrooming developments in communications technology. "A lot of our travel, which consumes energy at a high rate, could be replaced by much more effective communication," Seamans says.

It may be that communications will prove as fertile an



New opportunities. The world's energy crisis calls for intensive application of electronic technology to the power side of electrical engineering, says MIT's dean of engineering, Robert C. Seamans Jr. Building environment management is another promising market.

Multidisciplinary EEs. With hardware and software design merging, electronics engineers will become systems designers, says Paul C. Ely Jr., vice president of Hewlett-Packard's Computer Group. They will need both hardware and software expertise to function well.

area for EEs as will energy. Jean-Loup Delcroix, director of France's prestigious Ecole Supérieure d'Electricité, Gif-sur-Yvette, near Paris, notes that much work will be done in fiber optics and lasers. Also, says Seamans, "I expect that toward the end of the century you will not be able to determine directly where the communications system begins and ends and where the electronic data-processing system begins and ends."

Industry observers shy away from predicting the demise of any EE specialties. In one way they are saying that the next two decades will not represent so great a break with the past, but they are also saying that certain technical problems will endure. "Analog design will remain pretty much the same—we will probably always need an analog interface," remarks Thomas Slade, a microprocessor applications engineering manager at General Instrument Corp.'s Microelectronics Group in Hicksville, N. Y. Thus he sees a need for "classical analog engineers."

Nor do the demands of technology remain static, points out Liselotte Schulz, head of the error analysis group in the quality control section of Siemens AG's Semiconductor division in Munich, West Germany. "With solid-state devices becoming more and more complex, there will always be a need for painstaking testing by analytical techniques," she says. "In answering questions as to why there is a hole in the oxide or why ions travel under certain conditions, a computer is of little help. It does not replace the human mind with its capacity to analyze a problem."

An emphasis on applications will mean more across-the-board emphasis on marketing skills. Jim Lally of Intel notes that the systems area will certainly become more market-driven because microcomputer makers will need to solve a larger extent of the

In agreement are Ray Stata, president of Analog Devices Inc., Norwood, Mass.; Millennium Systems' Shanda Bahles; and Hewlett-Packard's Paul Ely. "I think an important element will be a strategic marketing understanding of how to mesh technology with its application in the marketplace," says Stata. "So I think the premium will come to companies that understand how the technology can be applied. The strategy used will be more technology-intensive."

Thus the EE will need a greater understanding of the interrelationship between user and machine than he had before, or what Steve Szygenda of the University of Texas calls human engineering. "Until now, human needs could readily be identified, and the engineer struggled to meet needs that were obvious," says William Gosling of Bath University. "In the future, increasing amounts of the engineer's time will be devoted to the perception of human needs and wants, perhaps in close collaboration with psychologists." Such a view puts the emphasis where it belongs, according to Dean Seamans of MIT: "I wouldn't necessarily call it a marketing orientation so much as a people orientation."

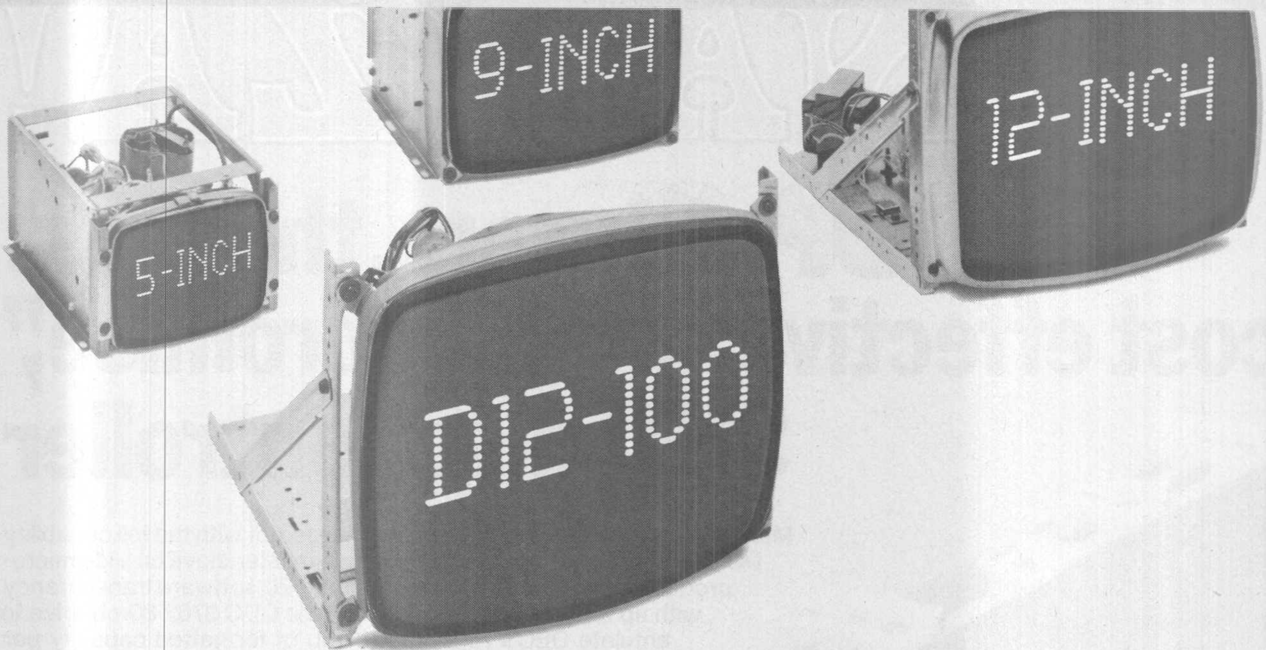
Kees Teer, managing director of electronic systems at the Philips Research Laboratories, Eindhoven, the Netherlands, expands on this point. He argues that marketing success will depend on the expertise of specialists in human behavior. "Human appreciation is a big question, and it is the job of the behavioral scientist to help answer that question," he says.

However, it is likely that EEs will move toward greater involvement with the results of their work, for that is increasingly the way of the world. Despite fluctuating political tempers and harsh economic times, a new spirit is loose that will not be quenched: a belief that the quality of life is a foremost consideration. "The engineer will have a lot more concern about how what he does affects his environment and about his relationship with society," says John F. Wilhelm, director of educational services for the Institute of Electrical and Electronics Engineers in New York. "Of course, this must be tempered with the employer's goals."

Perhaps it is beginning to seem as if the EE of the future will have to be a Renaissance man or woman, with talents and skills that span the universe of work. Actually, the engineer's qualifications in the next 20 years will differ little from those of today, although there is a distinct possibility that increasingly tough challenges will require increasingly well-qualified engineers.

One possibility is the development of the engineer as a multidisciplinary problem solver fueled by the trend towards more complex electronic solutions to more complex problems. The predicted merger of hardware and software design tells it all: the EE "will have to be a systems designer, an architect who knows how to design VLSI devices and who is competent in software," says HP's Paul Ely.

On the other hand, some observers see increasing specialization as the norm—a feature that has long been



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a fact of engineering life, says Analog Devices' Ray Stata. "One way we've dealt with the problem of technological expansion is to specialize in one small slice of it in terms of your productive work for a company."

As Stata is the first to acknowledge, specialization need not be a straitjacket, especially for the highly motivated engineer. General Instrument's Tom Slade joins him in anticipation of a broadening of the individual EE's vision by his switching specialties. "I think specialist areas don't take that long to learn," he says. Every few years the engineer could rotate, perhaps switching among related jobs. "When he returns to former specialties he could catch up with very little effort," Slade remarks.

John Wilhelm of the IEEE raises a related point: "The job assignments can be very specific, but they will change and probably at a much faster rate because technology is going down the learning curve." Stata agrees, although he sees much more of a challenge in specialization than Slade does: "I think the degree of that specialization will be more intense in the future."

As mentioned earlier, the trend towards the use of building blocks obviates the need for detailed knowledge of the circuitry. DEC's Gordon Bell says it is already leading to what he calls "upward integration of engineering skills." He adds, "Engineers seem to be moving from the domain of discrete component design continually upward to high levels of integration, and that refers not just to the components with which they make their design decisions, but also to the sort of skills they apply to the design problems at hand."

Millennium Systems' Shanda Bahles reports that from her perspective as a systems designer, there is no longer any need to know more than the rudiments of physics. "The IC houses are taking care of all analog problems," she states. "We can essentially ignore the electrical characteristics of TTL, for example, and treat the signal as a 1 or 0." Similarly, she believes it generally unnecessary for a computer designer to understand solid-state LSI processes. "But if you'd like to design a system with a view to an eventual changeover to an LSI chip, it would be nice if whoever is designing the system had some insight into some of the problems that are going to arise," she adds.

If such concerns as electrical characteristics and production processes become less important on the systems level, they will undoubtedly continue to be crucial at the chip level. Also, of course, IC designers will combine hardware and software expertise. One way to put it, says Jean-Claude Six, head of a design group at the applications laboratories of RTC-La Radiotechnique Compélec in Paris, is that "they will be specialists in functions and optimize them with a mix of microprocessors, software, and complex components. Engineers at nonelectronic companies like appliance makers will define the functions they want as black boxes, and the components suppliers will work out the best way to implement them."

In such fields as artificial intelligence, EEs will find themselves working with scientists from quite different fields, such as biology. "The mix will be an interdisciplinary one, with specialists from a number of different fields working on the same project," predicts Isolde Dietrich, a physicist who heads a team at Siemens' research facilities in Munich. Such a mix is not unheard of today; what will be exciting for EEs is the growing number of opportunities for them in such basic research.

Chip designers. When it comes to designing the integrated circuits of tomorrow, it will take designers who are specialists in functions, combining hardware and software knowledge to realize the new chips, says Jean-Claude Six of RTC-La Radiotechnique Compélec.

One way to look at the interplay between expanding career opportunities and an individual engineer's qualifications is to argue for an increasing bias towards tailoring a person's talents to the job. Still, that requires a healthy supply of EEs, and many industry observers are wondering if the manpower shortage of today is likely to become chronic. An important factor, in the U.S. at least, is demographic: zero population growth means relatively fewer candidates for engineering careers. Moreover, a shortage today has important long-term effects.

"When I think of the problems we're having today in terms of the scarcity of technical managers and engineers, I begin to realize that the really good ones have taken from 15 to 25 years of either education or related work experience to reach maturity as engineers," says Ray Stata of Analog Devices. "This means that 15 to 25 years ago, the education requirement had to be anticipated and clearly wasn't—and I think if we look ahead to 15 or 25 years from now, we'll have the same situation."

One interesting development, then, could be a change in the public's perception of the engineer—that is, to move the status of the job up to the level of a profession, like physicians, comments Tom Slade of General Instru-

ment. Stata argues that especially within the electronics industries, greater social value will be assigned to what he calls "the guru engineer."

What one finds now, he says, is that bright young engineers are motivated to become tomorrow's managers, primarily because these jobs are seen as the most desirable for career enhancement. Two factors will change this: "The scientific and engineering gurus are going to be so few and far between in the future, and so valuable as a result, that their contributions will come to be seen as more precious. . . . Beyond that, I think within companies there is getting to be a greater recognition that the product and technology decisions really are the fundamental underpinnings of high-technology industries, and the companies that have continued to show great success and progress tend to be companies where there is a very high level of achievement in the technological skills some place."

Of course, such a development will have considerable fallout among the general public, which will enhance the trend that Tom Slade sees developing. In fact, Siemens' physicist Isolde Dietrich sees a change in attitude developing towards basic research. "People are beginning to

Basic prestige. The general public is beginning to look with more favor on basic research in the sciences, believes physicist Isolde Dietrich of Siemens in West Germany. The reason is a greater appreciation of the important benefits to society of such research.

hold research activities in higher esteem and are recognizing the importance such activities have for society as a whole," she says.

One important direction in which this leads will be the engineer's role as ambassador of technology to the general public, says the IEEE's John Wilhelm. Bob Seamans of MIT agrees; he spends a lot of time doing just that and finds his speeches warmly welcomed.

The need for this role arises out of the increasing importance of technology in everyday life. More and more, political issues are likely to involve technology, and where public debate comes into play, people must decide technological issues.

"Unfortunately they are being forced to select among technological alternatives with very little technological knowledge and of course, this is where the engineer comes in—in the role of educator," Seamans says. "I think an engineer who goes out with the goal of helping people understand technological problems, as opposed to a sort of urge to uplift the masses, will find a sympathetic audience. I think he can be very candid and help a great deal."

With enhanced public respect for engineers, the desirability of the field may grow. John Wilhelm believes that and says: "I think the climate is going in that direction." Perhaps then the shortage of talent will not be as extreme as it now looks.

The lure of an engineering career will be more likely to attract more women and members of racial minorities than has been true in the past. Already there are signs that this is happening. The University of Texas's Steve Szygenda reports his school's enrollment is now 10% female, and that EE schools in general are beginning to respond to the pressure of the times by active recruitment of women.

It is not easy to guess how many minority EEs there will be, but the National Fund for Minority Engineering Students in New York can offer some interesting figures on the trend in all engineering schools. Of the 46,091 engineering undergraduates receiving degrees in 1978, 2% were black, 1.6% were Hispanic, and 0.1% were American Indian. However, of the 95,805 freshmen entering engineering school that fall, 5.7% were black, 2.8% were Hispanic (the University of Puerto Rico is not included in either Hispanic figure), and 0.2% were American Indian.

Of course, more is at work here than interest among the prospective engineers and pressure from the Government and representative groups. Companies are perceiving that they can help overcome the manpower shortages by encouraging a broader pool of applicants. "I think industry will be trying to do things that don't screen out women and minorities," says Ray Stata of Analog Devices. And TI software technology manager Roger Bate sees minorities and women as a way to fill the gap in program development; he notes that there is already a comparatively higher percentage of women in the field than before—"perhaps because it requires less in the way of heavy-duty engineering courses." As DEC's Gordon Bell points out, software engineering is an exam-

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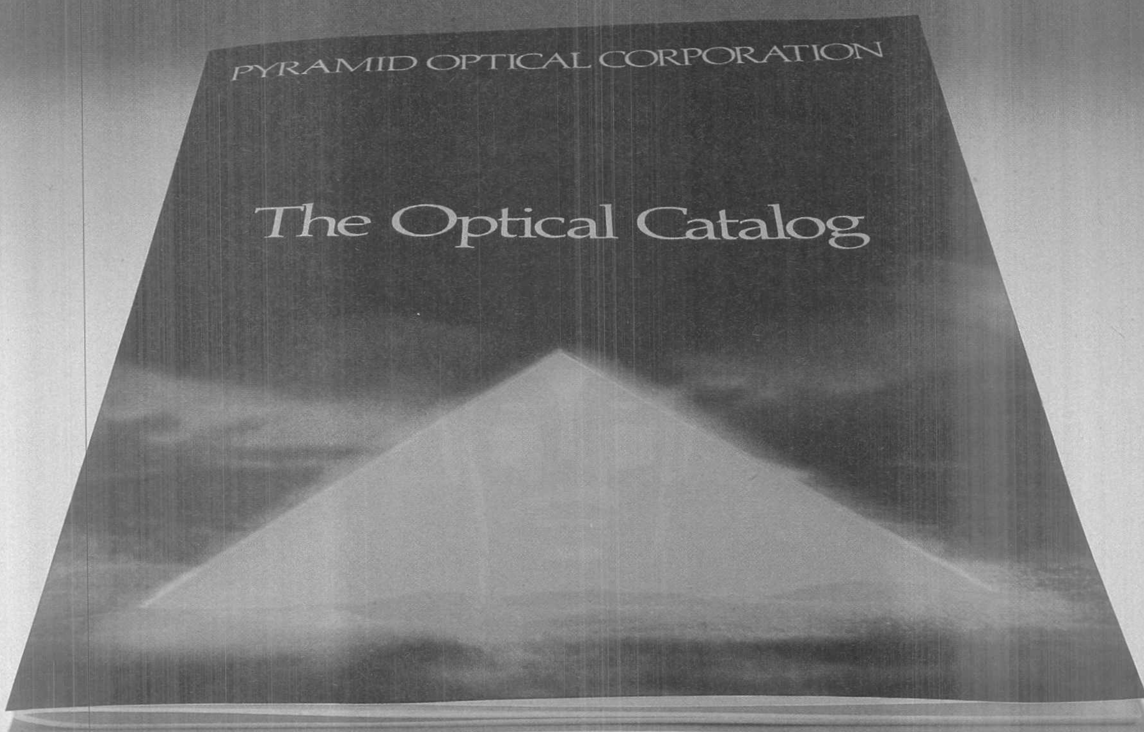

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Trying harder. Even in the most socially enlightened companies, professional women must try harder than their male counterparts in order to make equal gains in terms of promotions, says Hanni Kelle of Siemens' semiconductor quality control operation.

ple of the type of work that could be performed easily in the home once the wired nation truly arrives. Such a setup could also benefit another minority beginning to make itself heard: the physically handicapped.

Now that the walls are breeched, what welcome are the new groups of engineers finding? Shanda Bahles, who has worked for two young companies besides Millennium Systems, believes that of all the professional fields, "engineering has the least amount of bias. Engineers tend to judge on merit and technical ability."

However, Bahles goes on to argue, in effect, for Superwoman. "If they [women engineers] make it a point to excel, there will be no opportunities for those few [men] who are biased and are waiting to throw stones." Three women who have worked many years at Siemens support that argument. Isolde Dietrich and Liselotte Schulz report similar experiences to those of Hanni Kelle, a group leader in the quality control section of the semiconductor division, who says, "Women are not equal to men" when it comes to promotions. "One must try harder than men."

All three group leaders lay the blame on a lack of experience with women professionals; in fact, fewer than 1% of West Germany's engineers are women. Siemens has a little better than 200 women among its 20,000 engineers and researchers in domestic and foreign facilities, but that still makes the female engineer a rarity. Even so, the situation for women has improved, Schulz suggests. Throughout the industry only two or three decades ago, it was virtually inconceivable for a woman to hold a management position. That is still the case in France, where women engineers do not have the same career opportunities as do men, says Claude Iroulart, a group head at RTC-La Radiotechnique Compélec's Paris applications laboratory. "They get lower pay for the same job and cannot move up as easily because men don't want to work for women," he reports.

At the technician's level, Siemens is training a healthy number of women. At its Munich school for technical assistants, some 250 young women are attending two years of training. Those with degrees from junior colleges graduate as engineering assistants, and those with high school diplomas graduate as technical assistants. They follow courses in either communications or computer technology.

Of course, few other countries have the healthy percentage of racial minorities among their populations that the U. S. does. So there are hardly any movements afoot elsewhere to develop opportunities for minority engineers. The American push is going to reach fruition in about eight years, says Thomas L. Martin, president of the Illinois Institute of Technology, who recently completed a 2½ year stint as chairman of the National Research Council's Committee on Minorities in Engineering. Then the level of minority and women freshmen in engineering colleges will equal the level of minorities in the total population. It may take until 2010 for them to reach that level of representation in the engineering professions, he predicts.

Martin affirms the importance of the changing attitudes of the employers. The perception of discrimination discouraged minorities and women. "There was very little motivation to take the hard courses in high school and to take a hard program in college if you know you were not going to get the job anyhow," he says.

He also blames the high schools for inadequate preparation, particularly of minorities and women, a point on which he is supported by MIT's Seamans—who also singles out "inept guidance" in most secondary schools as a contributing factor. Even more critical is Gordon Bell, who is serving DEC while on leave as professor of computer science and electrical engineering at Carnegie-Mellon University, Pittsburgh, and who has a daughter in high school. Of the schools, he says, "I believe in fact that they can harm students. For example, there is a stereotyping of women with respect to mathematics: a negative stereotyping. . . . Now when you consider that engineering is based inherently on physics and mathematics, that says something about women and their entry as a group into the career of engineering. It's going to be impeded . . . by the parents, by their childhood environment, and it is certainly not going to be helped by secondary schools."

A number of observers see a related problem of a lack of role models because of the near invisibility of women and minority men in electrical engineering. Obviously, that lack is being corrected. No one mentions the success of Oriental men within the profession, perhaps because they have long since become part of the work landscape. If that is so, it augurs well for the acceptance of women

On the way up. That women are finding their way up the electronics career ladder is in evidence at Siemens, where a number hold important jobs. One is Liselotte Schulz, head of the error analysis group in the quality control section of the Semiconductor division.

and minority men in the engineering work force of 2000.

One notable obstacle for minorities is inadequate preparation, and Martin pleads for support for the special programs designed to overcome that problem: "These programs aren't something you start and think they are going to fuel themselves," he says. Retention rates at the college level are a related problem, observes John Wilhelm, who reports that the IEEE is focusing its minority effort on that and on identification of likely prospects for college entry.

There will be more than new faces around the offices and laboratories 20 years from now; the facilities themselves will look different. Again, this development is one that will occur unevenly, but by 2000, many EEs will work in a fully automated, highly computerized space—most likely still at central facilities, but perhaps with some spillover into their homes.

It takes no particular prescience to predict that the profession that spawned the computer, the minicomputer, and the microcomputer will capitalize upon its progeny. It is not just a matter of familiarity; it is the promised improvement in productivity. A consensus among industry oracles holds that computer-aided design and other computer-based tools are the answer to the twin dilemmas of too few engineers and increasingly complex design tasks. The computer will come to the rescue in both hardware and software design.

"Automation can reduce the ratio of drudgery to inspired work and the ratio of routine to judgmental activities," says Analog Devices' president Ray Stata. "Without that, there are some things that could never be developed within the lifetime of an engineer—they are just so complex." It is more than a matter of using a computer to model various alternative device configurations, emulate their performance, and aid in the layout, he argues. "You get into questions of a tradeoff of market requirements versus price elasticity—for instance, considering, as a function of various parameters, user options, which are things that can be in many ways modeled and can be more analytically factored into the design process than is the case today."

So computing power will pervade every aspect of many EEs' jobs. The workspace will probably be a work station not unlike those that are the forerunners of the office of the future, says HP's Paul Ely. "The EE will have a computer terminal and an experiment station with a number of computer-based instruments. Close by, there will be specialized laboratories with a few specialists in each. There will also be a place to take designs and have unique VLSI circuits made."

Because of the multidisciplinary nature of future jobs, "I see the EE of the future reading often. And when he is working, he will spend about half his time sitting at his computer terminal. I also see him writing and drawing a lot less than he does today, and a lot of things he used to look up in a file cabinet will be available to him in a computer." Nor will tomorrow's EE need a workbench or technicians' assistance as much as today, Ely says. "He can build a model or a product in software and test it in software from his terminal. All this will be an enormous assistance in reduction of documentation."

What goes for the future of hardware design also goes for the future of programming—and just in time, says Intel's Jim Lally. "The software engineer needs the same kind of advance as the hardware engineer got with VLSI." It will take computing power to bring that advance about; for example, Lally forecasts that the major tool that will increase productivity will be the increased use of high-level languages by software engineers.

Far down the road will come automated generation of software. "People have been working in this area for years, though we haven't had much success," says the University of Texas's Steve Szygenda. "But as the cost goes up and the pressures get greater, more emphasis will be put in this area."

If the next 20 years do not hold the promise of automated software generation, they will still see important advances in the art, both in terms of the tools that the engineers use and in the programming concepts from which they work. Among the former, Lally mentions automated performance-measuring tools; and among the latter, he includes structured programming, which imposes a discipline for error-free coding, and modular design, which links functional blocks by such design tools as linkers and locators, to permit more debugging.

At TI, Roger R. Bate and his associate in the advanced software technology department, Douglas S. Johnson, speculate that a special design language might evolve, and that it might include many English and high-level

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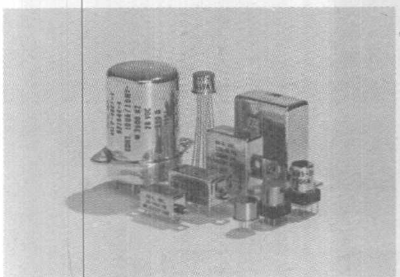

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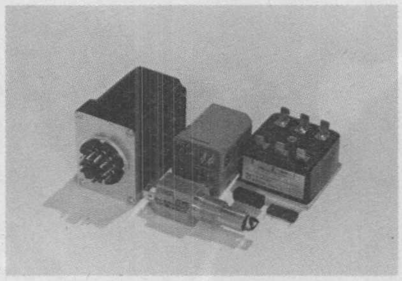

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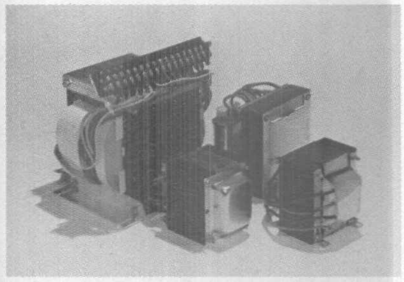

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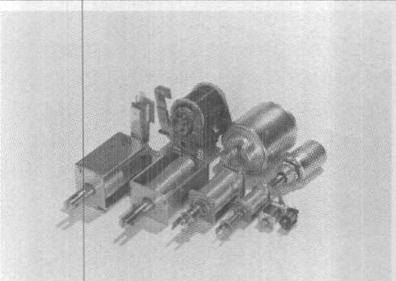

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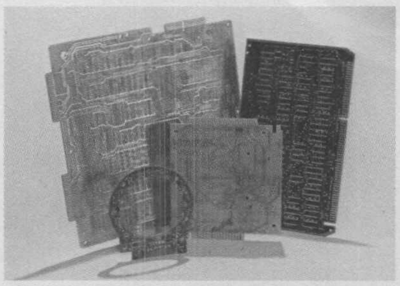

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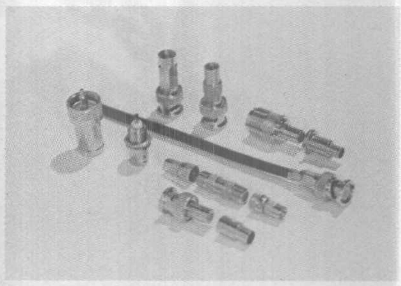

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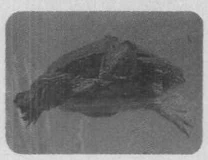

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programming language characteristics. (They also caution that while it is easy to invent a new programming language, it is hard to bring it into general use because of such factors as the high cost of development and training.)

Another possibility is text editors for program entry and management. These tools will be sensitive to the programming language in use and will check punctuation and syntax, thus relieving the programmer of that overhead. These tools will also track the changes made to program texts and will aid in the overall task of configuration management.

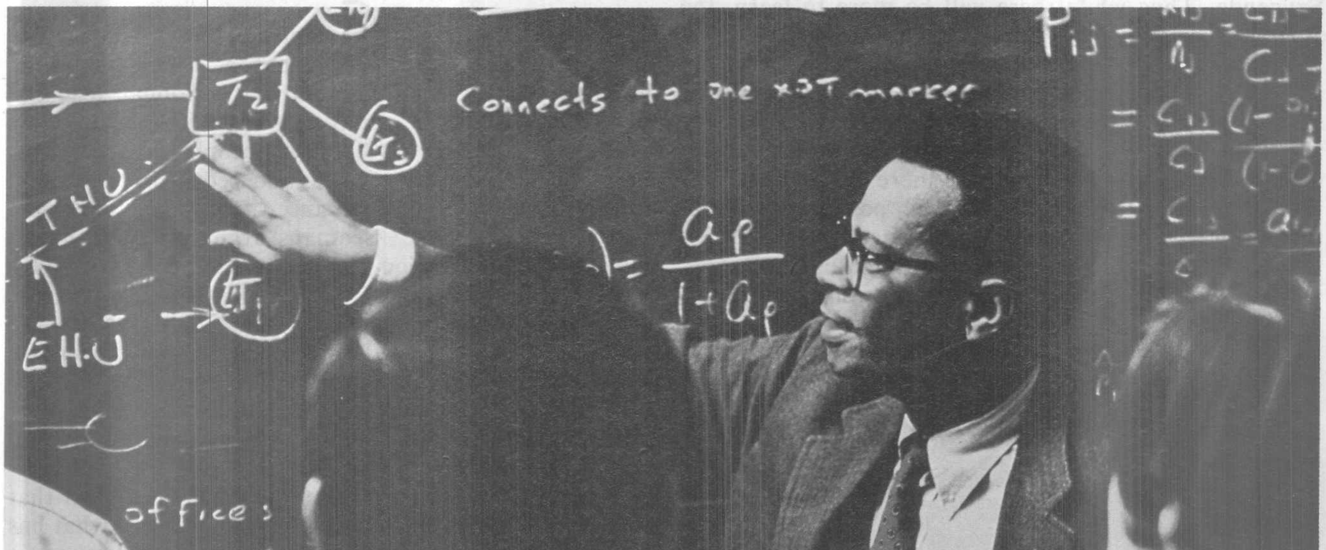
Also likely is a sophisticated assortment of testing tools. Today, testing complex software poses problems in selecting what data to put in in order to ensure that all branches that could possibly be traversed are checked. The programmer will need all the automated help he can get with the more complex programs of the future. According to Johnson, another testing tool (and one that will be one of the first to appear in common usage) will be source-level-language debugging tools—that is, software that can snapshot a running software program and transform the memory image into the symbols the programmer originally used.

Debugging also is an increasing problem with hardware, says Millennium Systems' Bahles. With more and more devices on a chip with a limited number of output pins, "the designer needs a more sophisticated debugging tool that is multifunctional and automatically refines data for the user so that he or she is not faced with a mass of signals that have to be interpreted."

The changing life of EEs certainly will affect their education through different curriculums, different study tools, and perhaps more time in schools. Some features of academia will not change, however, and one that industry forecasters almost unanimously see in the school of the future is an undergraduate education that emphasizes the fundamentals of engineering.

One problem that several of them foresee is that the list of basics will expand continually. With fabrication, design, testing, and software development coming together on the job, universities will be called on to produce "broadbased EEs who are going to have to know a lot about all of these areas," observes the University of Texas's Steve Szygenda. Of course, course content would have to be revamped, but it could be largely a matter of dropping the old in favor of the new. "We have gone from relays to tubes to solid-state devices, and we have changed our programs," he notes. "We don't teach much about tubes anymore."

Student engineers might indeed devote some time to a



Well-equipped. Not only will systems EEs need a broad-based technical education, but they must be prepared to disseminate their knowledge, as Bell Labs' Victor Ransome does in explaining an internal measuring system for the operating companies' traffic departments.

cautious," urges HP's Paul Ely. The content of most specialized courses will be obsolete by the time the students are through them, he says. "I see no letdown in the rate of technological change. In fact, there will probably be an acceleration." GI's Tom Slade agrees heartily and remarks, "It takes us six months full time to train a guy to become an MOS designer. So how can you do that in one course that meets once a week?"

One interesting direction towards which curriculums may move is "what you might call the engineer in society, and the question of to what extent in the undergraduate curriculum do we treat management, economics, environment, politics, geopolitics, and so on," says MIT's Bob Seamans. Similarly Tom Slade and the IEEE's John Wilhelm see a need for teaching communications and management skills.

Talks with educators suggest that the best picture of the new undergraduate curriculum will come from looking at today's graduate courses. They point to what might be called the trickle-down effect. "Many courses that were taught to graduate students only in the forties and fifties are now considered quite routine undergraduate courses," remarks Seamans. Not only is that true of computer programming, for example, but more than half of the University of Texas's freshman EE students have had some programming experience in high school, says Szygenda. Thus while there will be more to learn, the students may come better prepared.

A subject on which there is anything but a consensus is the amount of time the student EE will be spending in school by 2000. Will the undergraduate years stretch to five? Will the master's degree come to be the entry level into industry? Will there be more engineers with Ph. D.s? On all these questions, both positive and negative answers roll forth. One key factor, however, is identified by several observers, including Shanda Bahles, who says "undergraduate education won't last much

Career preparation. One way for companies to ensure women are educated for engineering jobs is to make a special effort to train them. Siemens' School for Technical Assistants prepares young women for jobs in the communications and computer divisions.

though it is, extended education is likely to be as important in 20 years as it is today. It is perhaps noteworthy that the two youngest EEs interviewed for this chapter are enrolled in graduate school: Bahles is on leave from Stanford University's master's program, where her emphasis is on computer hardware; and Tom Slade, whose undergraduate degree is in physics, is working on a doctorate in operations research.

Given that the working EE's tools will be undergoing some changes, the student's tools will probably follow. Educators expect the wide use of individual computer terminals or portable data bases, and these will—to a degree change the nature of education. "I can foresee as a teaching aid something that would combine computational ability and data-base access and a certain element of interaction with a student," says Gordon Bell of DEC and Carnegie-Mellon University. "Conceivably, the knowledge the student EE could call on would be much broader than that he calls on today. On the other hand, he would have to spend much less time learning it and would probably spend more time learning how to find or look up certain pieces of knowledge. . . . I believe the revolution is almost here right now, and that revolution consists of algorithms being in place so that information can be derived rather than stored."

Computing power may become as ubiquitous as the pencil, but a strong sentiment remains for the continuation of traditional teaching methods. Bell rather grimly attributes it to entrenched interests: "Schools have to put people in classrooms because they have classrooms, and people have to go to lectures at certain hours because there are lecture hours and schedules to fill." Seamans argues for the importance of the interaction possible in the classroom: "Obviously something is lost when you physically separate the instructor from the class—and when you tie the instructor down to something like video tape, there is still less flexibility in the learning situation." Along with other educators, however, he does anticipate more use of all forms of electronic delivery of information and of computer-aided instruction.

While Bell talks of a revolution, he makes it clear that he agrees with Seamans in rejecting the idea of what has been called the computerized campus. Such a scenario envisions a vast communications network linking myriad data bases, with every student and teacher gaining easy access through individual computers or smart terminals. Bell points to the size, complexity, and regimentation of such an undertaking, noting that "it will require too much agreement among a population composed of scholars preoccupied with intellectual freedom." Seamans asserts once again that the setup would replace actual experience with an unsatisfactory alternative. "Anything that is in the can is not the real world."

Another problem with the computerized campus and with sophisticated new educational tools is a longstanding headache for academia: cost. Not only do courses require increasingly expensive laboratory equipment, Seamans says, but more and more "require far more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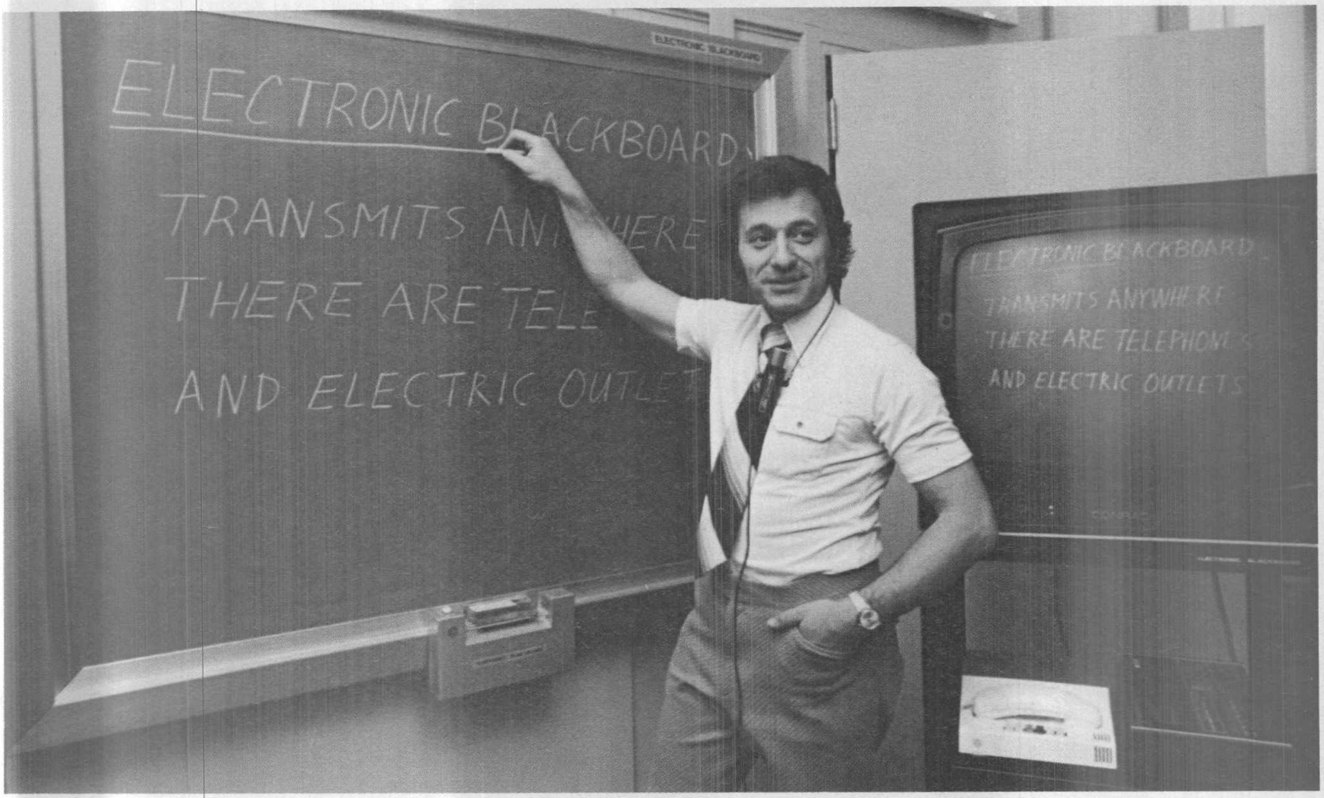


Electronic aid. Likely to become familiar in far-flung companies is such equipment as AT&T's Gemini 100 electronic blackboard. Behind the surface are pressure-sensitive plates that convert chalk marks into electric signals for transmission over phone lines to video monitors.

computer time than is presently easily available."

What all this means, according to the MIT dean, is that labs "are not at the cutting edge of technology in many cases." Tom Slade says that computer experience is the crucial factor, especially for developing programming skills and systems analysis. But he dismisses the rest of the equipment problem; he argues that student laboratories are little more than a taste of the real thing. "Labs are a waste of time until you get into industry where you spend eight hours a day in them," he says.

A number of observers anticipate that the zooming costs of education will be met in part by a variety of industry contributions. For starters, both Shanda Bahles and Steve Szygenda say, companies could donate advanced equipment for the labs. Of course, the geometrical increases in equipment costs are making many companies wonder how they can afford them for themselves. The alternative, suggested by Seamans, is to take the student to the equipment. Internships can give access to state-of-the-art tools; moreover, they give "a chance first of all to learn about the real world and how things are done, while they are still undergraduates and able to structure their electives to suit themselves better to life in the real world." Tom Slade thinks internships or some equivalent could be equally valuable on the graduate level, and could replace the dissertation, of which he says, "The absolute specialization of this is useless."

Opinions are mixed on whether companies will move beyond equipment donations to more active financial involvement. Analog Devices' Ray Stata looks for increasing interaction in order for industry to get across its educational needs. Alumni participation is one route, but even more important are industry funds for consulting services and for research. Such money has been coming mostly from the Government, he says, so it "has had an incredible influence on the direction academia has taken." On the other hand, Steve Szygenda argues that companies traditionally have been reluctant about financing university research for fear the results would enter the public domain.

Across the Atlantic, Great Britain may well be moving towards a closer interrelationship between industry and academia, says Bath University's William Gosling. The impetus might be a major overhaul of the educational and professional structure of engineering, says Gosling, who is serving as president of the Institute of Electronic and Radio Engineers. The root of the problem is Britain's emphasis on pure science and a consequent downgrading of application. What is needed, he says, is the creation of a highly rewarded engineering elite.

What Gosling and many in British industry hope for is a three-tiered educational structure for engineers, technician engineers, and technicians educated by, respectively, universities that become centers of technical excellence, colleges of technology, and polytechnic schools. He also argues for a measure of flexibility in the framework and in careers to avoid the rigidity of educational qualifications that is so strong a part of Britain's class structure.

For an example of the involvement industry might have with educational institutions, Gosling points to the cooperation between his university and General Electric Co. Ltd. A master's in engineering program, an intensive 4½-year course, mixes carefully structured internships

Easy dialing. For a true hands-off phone, Bell Labs is working a voice-actuated repertory dialer. The unit will store some two dozen numbers, referenced by the words the user stores with them. Marrying the analog and digital worlds will be an important design area.

with GEC and classroom work. The impetus for GEC was its strong dissatisfaction with shortcomings in the average undergraduate's education.

In the U. S., dissatisfaction is not with postsecondary education but with the quality of high schools and presecondary schools. Seamans reports that MIT tests incoming graduate students for ability in reading, writing, and speaking English, "and the percentage who are lacking in these communications skills is incredible. We are talking about 20% or 30% of students at the *graduate* level needing remedial work in English." And Tom Slade reports with dismay that the high-school calculus course he took no longer exists.

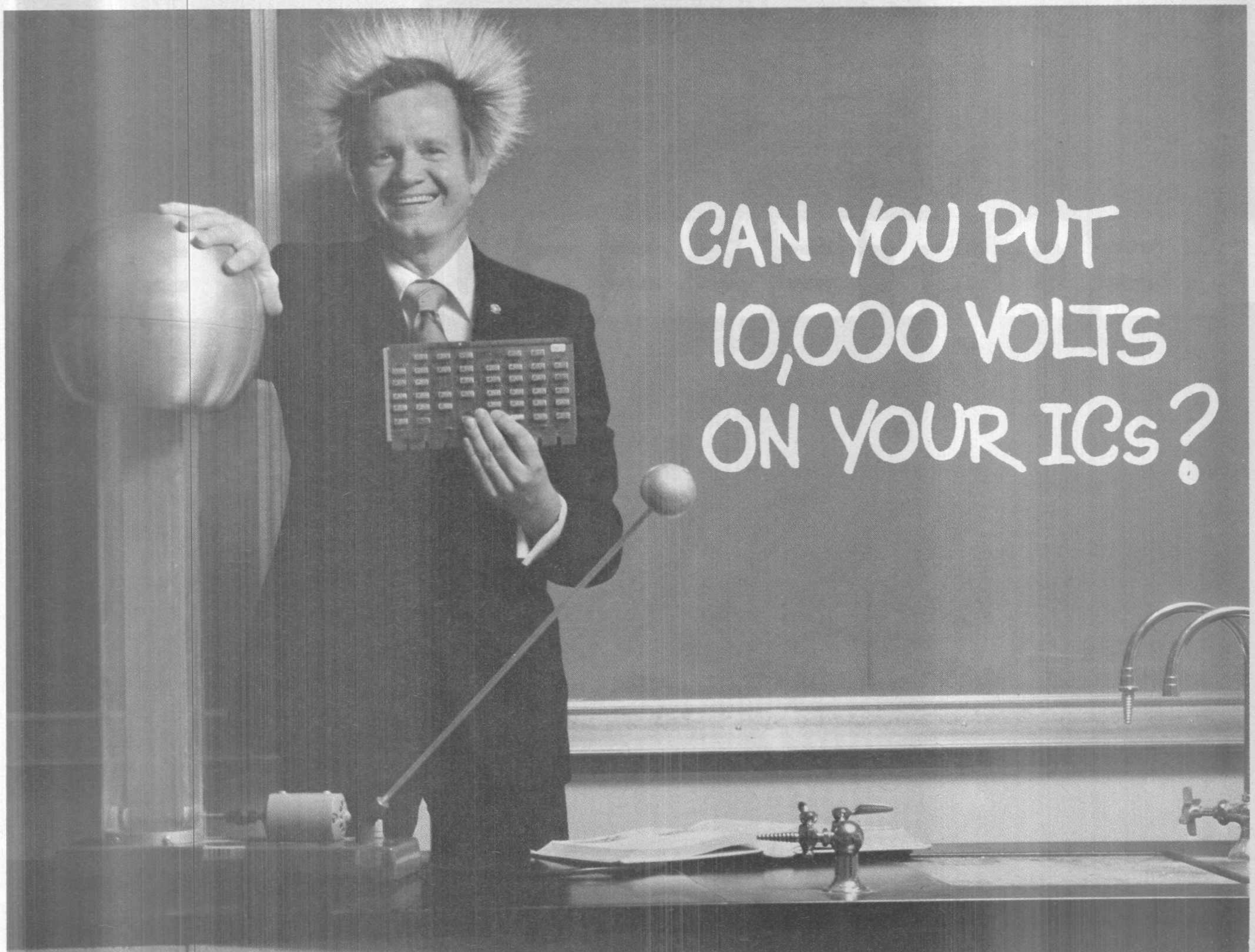
There is a desolate joke to the effect that the 21st Century will be called off, due to lack of interest. The optimists in the industry do not see that happening, for they expect interest in such demanding work as engineering to rekindle with an increase in the students' demand for tough preparatory courses. A good lodestar may be the use of scientific calculators and home computers. If high school students take to them and if they seek courses that use them in significant new numbers, then secondary science education in the U. S. may well flourish.

Even with the problem of ill-preparedness solved, the postsecondary schools face another critical obstacle in the opposite direction. Steve Szygenda says that the massive needs of industry mean that universities are unable to attract qualified new faculty members because of salary differentiation. Not only are few bright young EEs choosing careers in education, but few engineers with industrial experience are opting to move into the universities, he says.

What he sees as a solution is for engineering schools to move to professional status, like law and medicine. (Of course, some forecasters already see engineering as a career moving in the direction of professionalism.) With separate status like this, faculty salaries can be much higher than in other disciplines, he maintains. Without it, the quality of graduates will fall drastically, and industry will be forced to pick up more of the educational burden in house.

John Wilhelm of the IEEE has noted discussion of what some engineering professors see as the first wave of the problem. It is the increasing presence of foreign-educated teachers. Without experience in U. S. schools or companies, their understanding of American industry is questionable—or so the argument runs.

For many EEs, education continues as they advance in their careers, and that feature of their worklife will still be around at the turn of the century. As the microprocessor has boomed, continuing education has boomed; as



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the digital revolution rolls on, engineers will continue to go back to school, or take short courses, or sign up for self-study courses.

Ray Stata of Analog Devices points out that reeducation sponsored by companies could become a key ingredient in meeting the manpower shortage. Right now it may be cheaper to hire a new college graduate and fire the experienced but unprepared man, but increasingly companies will not have that choice, he predicts. "The issue of obsolescence as a result of changing technology and opportunity is one that has been with us all along and is still with us, perhaps to an accelerating degree," he says. "But I think the answer to it is . . . continuing education." Tom Slade disputes this viewpoint. He says that in his experience of interviewing job candidates at GI, "The ratio of good to bad EEs is running 50:50. . . . Age matters very little; I'll bet the obsolete engineers were obsolete when they left school."

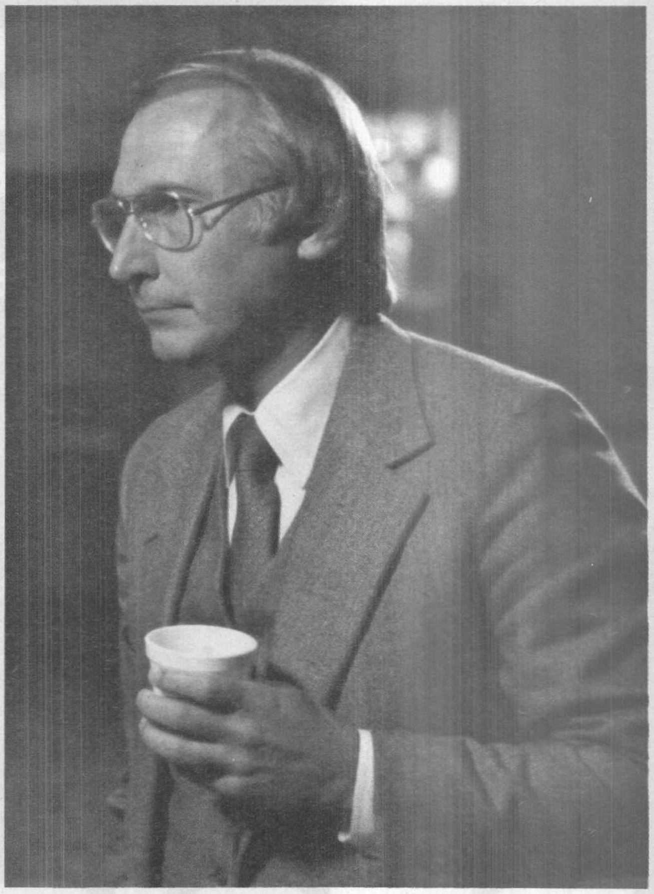
What counts, says Stata, is the self-motivation of the individual engineer. Both Paul Ely of HP and Shanda Bahles of Millennium Systems see a lot of motivated EEs out there. They do not foresee significant increases in time spent on continuing education, simply because engineers are already putting as much time as they can spare into studying. Bahles expects company-sponsored education to continue to be popular, but new emphasis to go to self-study programs. She thinks formal continuing education will become less important because "five years out of school, whether you have a master's or a bachelor's degree makes no difference."

John Wilhelm confirms that the IEEE sees its members' acceptance of home-study courses growing but so is interest in any type of class that offers leading-edge technology. Another possibility would be midcareer internships, with both teachers and employed EEs moving into the other sphere of activity for a while.

Yet something else might happen, says DEC's Gordon Bell. "There will come a time when there will be programs available—software, that is—that are of such sophistication and utility that they might make continuing education much less necessary than it is today." The hard work has already been done and need only be reduced to software. "One way of dealing with a lot of these very complex problems like continuing education and like the problems that engineering has solved is by packaging them and treating them like black boxes."

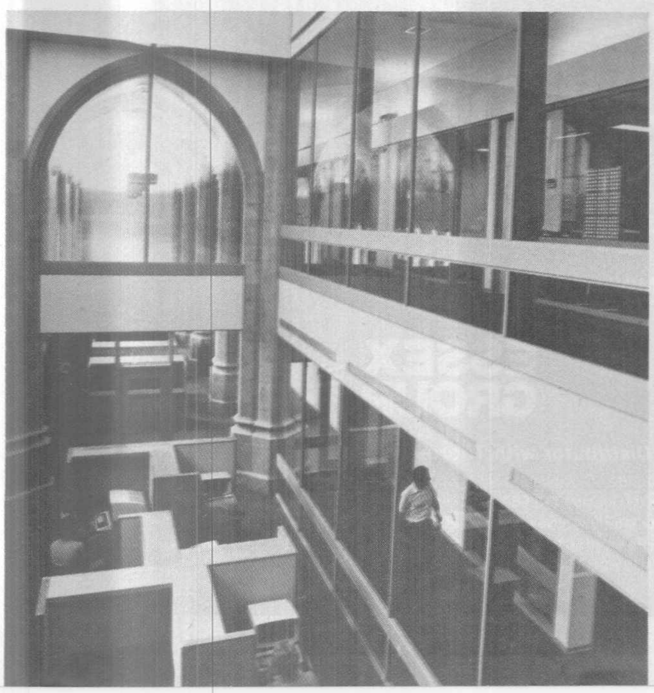
What Bell suggests has crucial, perhaps frightening, implications for the EE of the future. "I think that an engineer is basically a person with great intellectual curiosity whose skills lie in structuring complexity—solving problems in that fashion," he says. "I think his skills and his intellectual curiosity may be all he needs in the next 20 years to carry him through. He will either educate himself if he needs to be educated or learn to use the black-box, algorithmic approaches I've just mentioned to solve problems."

Yet, how alive will skills and intellectual curiosity stay if the person possessing them is simply plugging in software? Will not technological advance deteriorate if the collective level of intelligence atrophies? Perhaps Bell is only painting a picture of the routine, and the technological and social problems that remain will challenge the truly skilled and truly creative engineer—and with any kind of luck, perhaps there will be enough of these EEs to go around. □



Retraining a key. What with the shortage of electronics engineers, companies will find it wise to invest in retraining, says Analog Devices' president Ray Stata. In fact, the troubling notion of an obsolescent EE itself will become outmoded, he maintains.

Strange bedfellows. One educational trend likely to pick up speed is increased use of computers. Rensselaer Polytechnic Institute, for example, installed a major new computing center, ingeniously converting a former church (and then a library) to house it.



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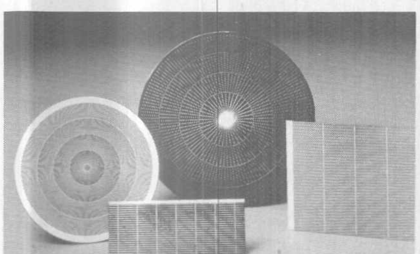

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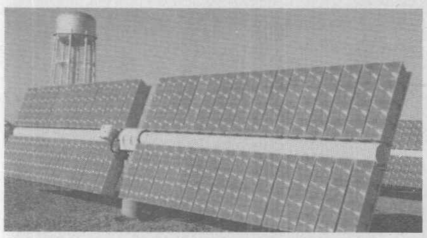

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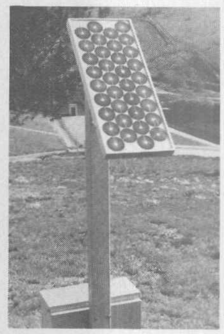

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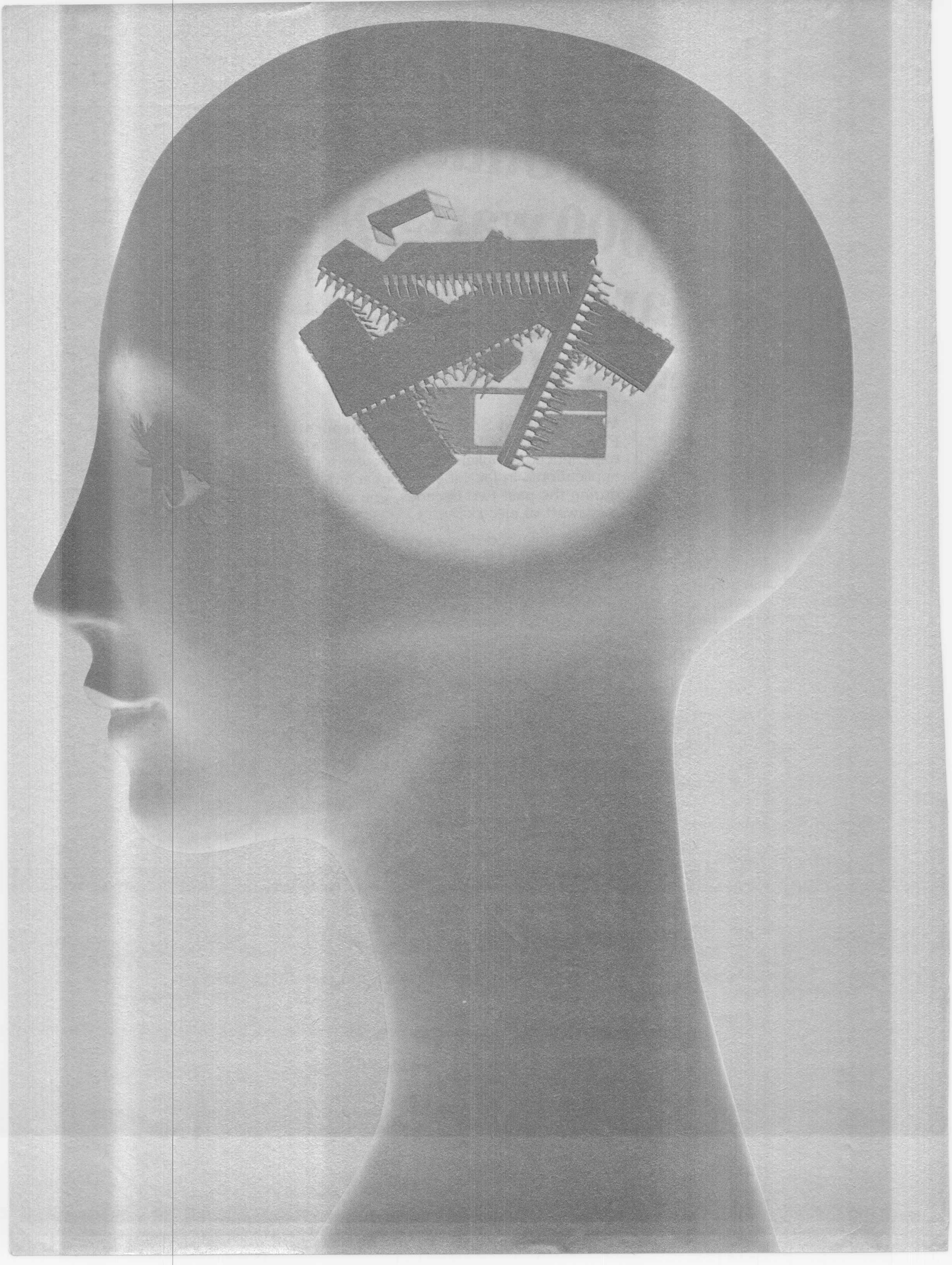

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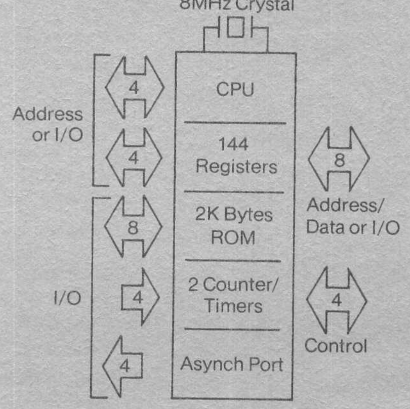

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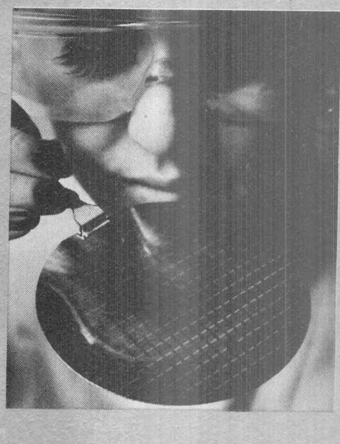

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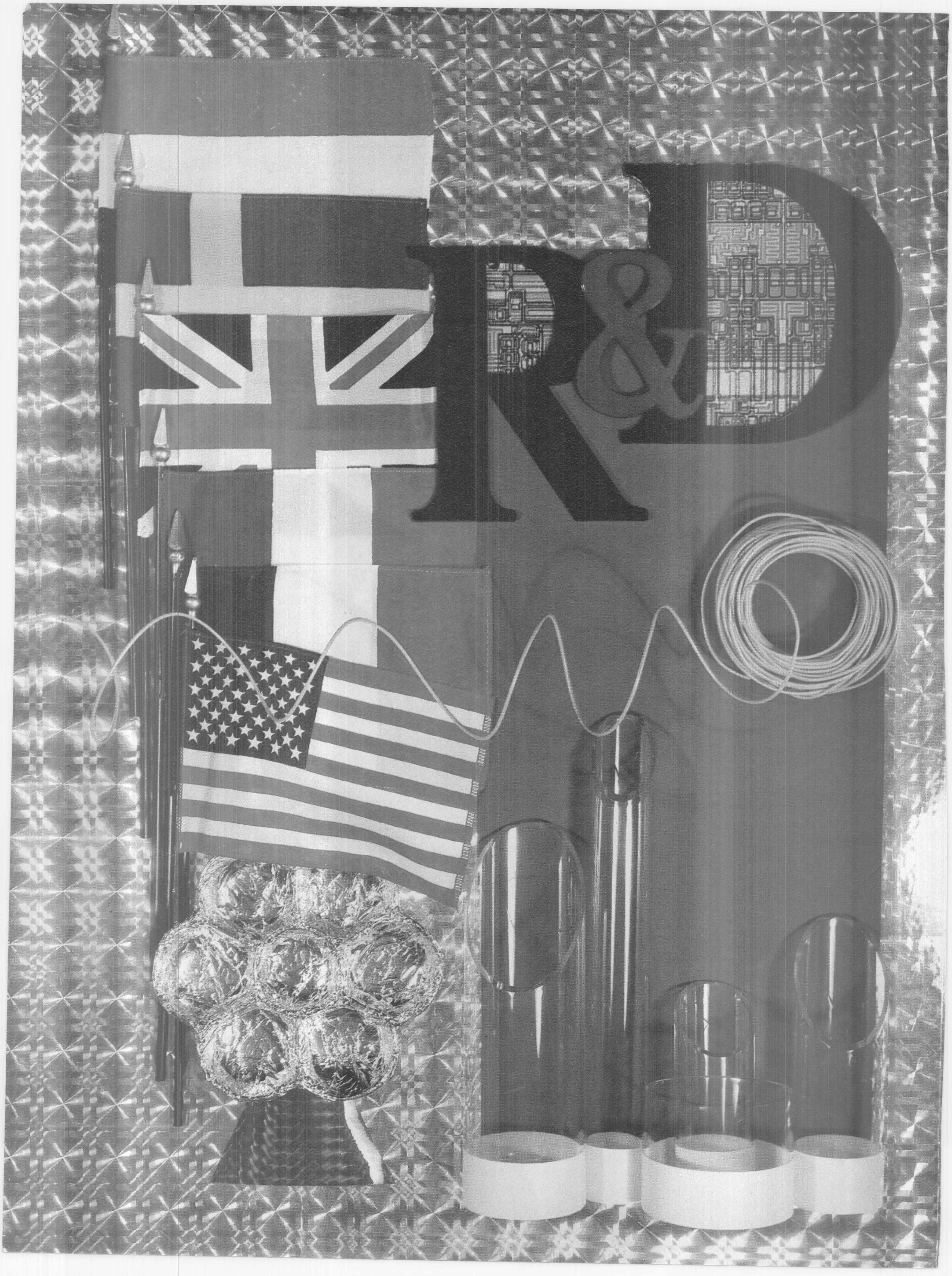
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IN SHAPE AS WELL AS IN SUBSTANCE THE ELECTRONICS INDUSTRIES WILL CHANGE BY THE TURN OF THE NEXT CENTURY. THE MOST DISCERNIBLE MOVEMENT WILL BE AN ACCELERATED INTERNATIONALIZATION. A CONSOLIDATION INTO A FEW LARGE ACROSS-THE-BOARD MULTINATIONAL COMPANIES COULD HAPPEN, WITH NICHES LEFT FOR SOME SMALL SPECIALTY HOUSES. ALMOST CERTAINLY THERE WILL BE A ROUTINE EMPHASIS ON WORLDWIDE SALES BY COMPANIES OF ANY SIZE. NORTH AMERICA'S GRIP ON INNOVATION WILL LOOSEN, AND ELECTRONIC TECHNOLOGY WILL BECOME TRULY THE PROPERTY OF NO SINGLE NATION OR GROUP.

Getting together. Panelists are (standing, left to right) Standard Microsystems' Paul Richman, Bell-Northern's Gordon B. Thompson, and Intel's Gordon Moore. Seated are (left to right) IBM's Ralph E. Gomory, TRW's Simon Ramo, Carl Carman, and TI's George Heilmeier.

The electronics industries will look different 20 years from now, at the start of the 21st Century. That is an easy prediction, in the light of the last 50 momentous years.

Now comes the difficult part: just how different will the electronics industries look? Will the structure be close to today's, with recognizable companies making recognizable products, or will there be an evolution toward just a few large, broad, and all-encompassing supercompanies dominating every market from consumer to communications, industrial to defense? It can be argued that such a movement is already under way, what with semiconductor makers spreading into the computer business and computer manufacturers extending into the communications industry, and so on.

Here is another conundrum with which to wrestle: were such consolidations to happen, where would the innovation come from? Traditionally, advances in electronic technology have emerged from the small, shoestring operation started by an entrepreneur who had an idea and wanted to bring it to the marketplace. If such operations no longer flourish, will there be room for such pioneering in a supercompany with its carefully structured parts and its zealously guarded table of organization? Is not the nature of such concerns to busy themselves with making and selling many products rather than to nurture innovation?

Another current is running strong through electronics: internationalization. The world of technology is shrinking. Roughly 50% of the advances are now coming from the U. S., but that is a sharp reduction from the years when the rest of the world was years behind the Americans in introducing new ideas. Japan and Western Europe are no longer imitators; what will they be at the turn of the century?

With all these forces for change, it may seem that evolution is inevitable. Yet there are certain limitations that must be taken into account: limitations to what people can accomplish, to what the industries can do, and, of course, to what the technologies can do. The question is whether any of these limitations is insurmountable, or if any will hinder progress.

There is no question that the fields to watch will be computers, communications, and semiconductors. Within these fields, however, there are manifold considerations to ponder when forecasting the shape of things to come. Advances there will be, but what kinds and how significant?

This is where we stand as the ninth decade of the 20th Century begins. Things are changing: just how much will they change in the next 20 years?

Prognostication is at best a chancy business. However, the people best qualified to foretell the shape of the future are those who have done so much to mold the present. *Electronics* has asked some of those leaders of the electronics industries to look 20 years down the road. The magazine's editors interviewed

them around the world, at their workplaces, on the move between cities, and even in their homes.

The centerpiece of those efforts, however, was an extraordinary convocation in New York. In an all-day discussion with the editors on Sept. 13, 1979, they offered their vision of what the electronics industries will be like in the early years of the 21st Century. Those industry heavyweights were:

■ Carl D. Carman, then vice president for engineering at Data General Corp. in Westboro, Mass., where his responsibility was the engineering of computers, peripheral equipment, and related products for the minicomputer maker. He is now vice president for engineering at NBI, a Boulder, Colo., word-processor vendor. He has served as assistant to the president of Storage Technology Corp. in Boulder and as director of engineering at Inforex Inc. in Burlington, Mass. He has bachelor's and master's degrees in electrical engineering from the University of Kentucky.

■ Ralph E. Gomory is responsible for International Business Machines Corp.'s Research division laboratories in Yorktown Heights, N. Y.; San Jose, Calif.; and Zurich, Switzerland. A mathematician, he has been with IBM since 1959 and was appointed director of research in 1970. He has published more than 40 papers in pure and applied mathematics and in 1964 was winner of the Lanchester Prize of the Operations Research Society of America. Also in 1964, he was named an IBM Fellow. He was a member of the council of the National Academy of Sciences in 1977–78. He received his BA from Williams College and his Ph.D. from Princeton.

■ George H. Heilmeier, vice president of research, development, and engineering at Texas Instruments Inc. in Dallas. He holds 15 patents in molecular and liquid crystals. As assistant director of defense research and engineering for the Department of Defense from 1971 to 1975, Heilmeier formulated major new initiatives in microwave tubes, fiber optics, infrared systems, charge-coupled devices, and radiation-hardened complementary-MOS devices on sapphire; he then served as director of the Defense Advanced Research Projects Agency from 1975 to 1977. Before those stints, he was at RCA Laboratories in Princeton, N. J., from 1958 to 1970. He holds a bachelor's degree in electrical engineering from the University of Pennsylvania and a master's and Ph.D. from Princeton.

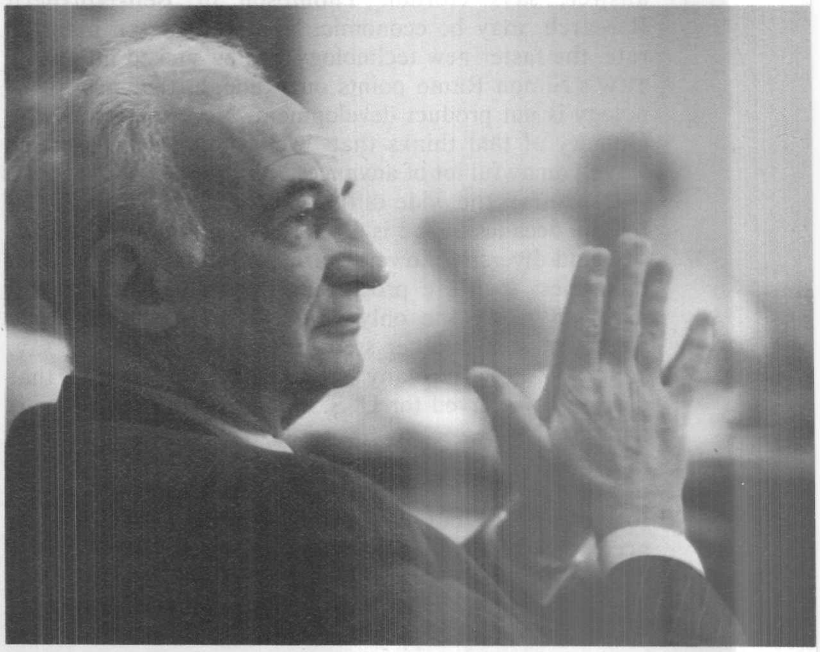
■ Gordon E. Moore, chairman and chief executive officer of Intel Corp., Santa Clara, Calif. He was a member of the technical staff at Shockley Semiconductor Laboratory and director of research and engineering for Fairchild Semiconductor before going on to found Intel with Robert Noyce. He holds a bachelor's degree from the University of California at Berkeley and a Ph.D. from California Institute of Technology. He received the first *Electronics* Award for Achievement.

■ Simon Ramo, vice chairman of TRW Inc. in Cleveland and chairman of its executive committee. He served as the chairman of the President's Committee on Science and Technology, 1976–77; on the Advisory Council to the Secretary of Commerce, 1976–77; and as a member of the White House Energy Research and Development Advisory Committee on Science and Foreign Affairs, 1973–75. He is the author of "Cure for Chaos" (1969), "Peacetime Uses of Outer Space" (1961), and "Guided Missile Engineering" (1959). He holds a BS from the University of Utah and a Ph.D. from California Institute of Technology. He has been president of Space Technology Laboratories and chief scientist of the U. S. intercontinental guided missile program and was a founder of the Ramo-Woolridge Corp. He is a 1979 winner of the National Medal of Science.

■ Paul Richman, president of Standard Microsystems Corp., Hauppauge, N. Y. He holds the basic patents for the Coplamos and Clasp MOS technologies and is author of "MOS Field-Effect Transistors and Integrated Circuits" (1974) and "Characteristics and Operation of MOS Field-Effect Devices" (1967). He was vice president for R&D at Solid State Data Sciences Corp. and a senior development engineer at General Telephone & Electronics Corp.'s central research laboratories. With a BS in electrical engineering from Massachusetts Institute of Technology and a master's from Columbia University, he is a visiting professor of electrical sciences at the State University of New York at Stony Brook. He received *Electronics*' 1978 Award for Achievement.

■ Gordon B. Thompson, manager of communications studies at Bell-Northern Research Ltd., Ottawa, and the holder of 13 Canadian and 11 American patents. In his career with Bell-Northern Research and Northern Electric, he has worked as development engineer for communications equipment and a supervisor of audio and video products and systems design and has made studies of information technology and socioeconomic systems.

In evolving a scenario for the next 20 years, the participants in the forum managed to arrive at a consensus. Since no one can predict revolutions, what emerged is a belief that change would be evolutionary, a continua-



World competition. TRW's Ramo sees a "contest between a free world economy, in which money and resources move freely around the world, and the isolation and protectionism of some national groups" still going on 20 years from now.

tion of forces already set in motion by the enormous technological impact of solid-state circuitry and, more particularly, the computer and the microprocessor.

Intel's Gordon Moore perhaps put it best when he said that the structure of the electronics industries would not change so much that it would be unrecognizable.

"I see a general split between companies whose principal business is in making the hardware and companies whose principal business is in applying it to the solution of the problems. It's not going to be a clean split: most companies will have some distribution across the entire spectrum. But companies will tend to peak their capability in one direction or the other."

However, Moore expects that technologies will not be restricted to just a few companies apiece. "I'm sure we'll see the general technologies that are important much more broadly diffused through the industry. Any significant systems company will have a significant solid-state electronics operation, for example, and vice versa. But the electronics industry is going to be very, very diverse. While it's going to have a number of large companies, it's still going to have a very large number of relatively small companies that will specialize in particular areas."

This setup will carry over even into the components business, says Moore. In semiconductors, for example, "there will be a number of producers of relatively large quantities of standard products; there will be a lot of companies producing more for their internal systems. This will result in a lot of different companies doing semiconductor work. That's been a dramatic change over the last half dozen years already."

But will there be any major technological changes in the next two decades? The answer, says Gordon Thompson of Bell-Northern Research, may be economic: "The higher the inflation rate, the faster new technology will be sucked into use." TRW's Simon Ramo points out, though, that new technology is not product development. Nevertheless, Ralph Gomory of IBM thinks that "we're going to wiggle our way to an awful lot of advances."

Of course, the wide diffusion of technology predicted for the decades ahead is already under way. Such diffusion and diversity, however, are not limited to individual industries: they are proceeding apace, with the planet itself providing the only boundaries. In the past five years, news of another step forward coming from, say, Japan or West Germany has received the attention that used to be reserved for U. S. developments only. That is a major change.

Gomory warns that while other people have been used to getting ideas from abroad, the sensation is a new one for Americans but one that they had better become accustomed to. For example, he says, "the pace of discovery in Europe is equal to that of the U. S., whereas it wasn't a short time ago. We may have ideas, but other nations sometimes apply them faster."

Such technological parity is accompanied by increased investment of foreign firms in American companies, as well as takeovers by big U. S. firms. "I don't see it going completely that way," says Moore, "but there are rela-

Europe looks toward the 21st Century

With advanced electronic technology becoming a worldwide phenomenon, any prediction of the shape of the next 20 years must include the views of overseas industry leaders. In Europe, for example, many leaders expect consolidation and internationalization to shape the electronics industries—but many also think the U. S. will comfortably maintain its technology lead through 2000.

One of the best-qualified companies to undertake such prognostication must be NV Philips Gloeilampenfabrieken of Eindhoven, the Netherlands. With sales in 1979 of more than $17 billion, Philips is a multinational company—it prefers to call itself a "federation of companies"—that is by far the largest of the electronics conglomerates outside of the U. S.

The most striking change, as enunciated by Winfried van 't Hoff, director of the firm's components division, Elcoma, is one of maturation. "The stage when a few geniuses set the pace has long since passed," he says. "Solid-state production has become too capital-intensive and the market positions too entrenched for a new small company to find an opening." Leo Heesels, a member of Philips' 11-man board of management, agrees with this point of view. "For many advanced products, an integration of several technologies is needed," he says, "and small companies don't have broad enough applications know-how to embrace them all."

Ferdinand Rauwenhoff, Elcoma's managing director for production, believes that the increasingly sophisticated solid-state technologies seem sure to be worked only by giant companies. But that is where the smaller firms also will find a niche: they will be able to strike oil where the software content of a system or product is high.

At ITT-Europe headquaters in Brussels, Karl M. Schmidt, audio product line manager, predicts that if the U. S. does not have another space program, "its technology lead could be cut from 50% to 30% by 2000." Speaking of semiconductors, Jack Shields, technical director, pinpoints first-class manufacturers of production equipment as the pacing factor in the U. S. dominance. The Japanese? "I don't see them gaining the upper hand in semiconductors," says Schmidt, "because in Japan demands for better living will increase and costs will go up."

Marketing director D. M. Hamm thinks that if the U. S. can still nurture small companies it will maintain its semiconductor lead because smaller companies are so close to the marketplace.

In computers, the ITT officials see changes coming about because of software costs. "I see a shift in training engineers from hardware to software," says Schmidt, adding that the costs will mean that software will no longer be a free service.

ITT-Europe vice president Heinz Roessle has a slightly different view of the shape of the industry. "The trend toward diversified company structure will accelerate," he says. Member companies of large international organizations—like ITT—will increasingly cooperate across national boundaries. This will make sense because national markets will be too small to support the companies.

Such strategy, adds Roessle, also will benefit small companies "if they are prepared to take risks and think international." He points to Intel Corp., the Santa Clara, Calif., semiconductor leader, as one that has succeeded with just such a strategy. He is convinced that the U. S. will maintain its lead in electronic technology for some

Philips seers. Ferdinand Rauwenhoff (left) says new solid-state technologies will emerge from big companies. Winfried van 't Hoff believes that small firms will not find an opening.

Bigness will win out. Leo Heesels, a member of the Philips board of management, thinks that small companies will be unable to handle the needed integration of several technologies.

time to come because it has "the kind of society that fosters innovations, a society that rewards those who advance technology and open up new frontiers." As for Japan, Roessle believes that it will play a pace-setting role in many technical fields.

In France, opinion also leans toward the consolidation scenario for the electronics industries. Erich Spitz, director of Thomson-CSF's central research laboratory in Orsay believes that "real, serious research will be done almost exclusively in large labs." The reason: "Everything will be conceived in terms of large complex systems," making it virtually impossible for small or even medium-sized companies to carry out major research programs.

On the whole, he believes that the U. S. will keep its position as the technological leader, even though internationalization is inevitable. "The differences between American and European companies will grow smaller and smaller. In 20 years, all large companies will be international companies," he says. The Czech-born research chief says that electronics will play a major role in solving problems that threaten the very existence of mankind. "It may stem from an energy crisis, or something else. In 20 years, hundreds of thousands of electronics engineers may be working on solutions to energy-related problems. As a spur for new technologies, "the energy crisis might well turn out to be akin to World War II."

For Jean-Claude Pelissolo, director of the French government's electronics and computer industry agency, the Direction des Industries Electroniques et de l'Informatique, it is a foregone conclusion that the future will hold more multinationalization. Pelissolo, who is also a member of the board at CII-Honeywell Bull, the large French computer maker, adds that many of the largest groups will be based outside the U. S.—possibly in France or other European countries.

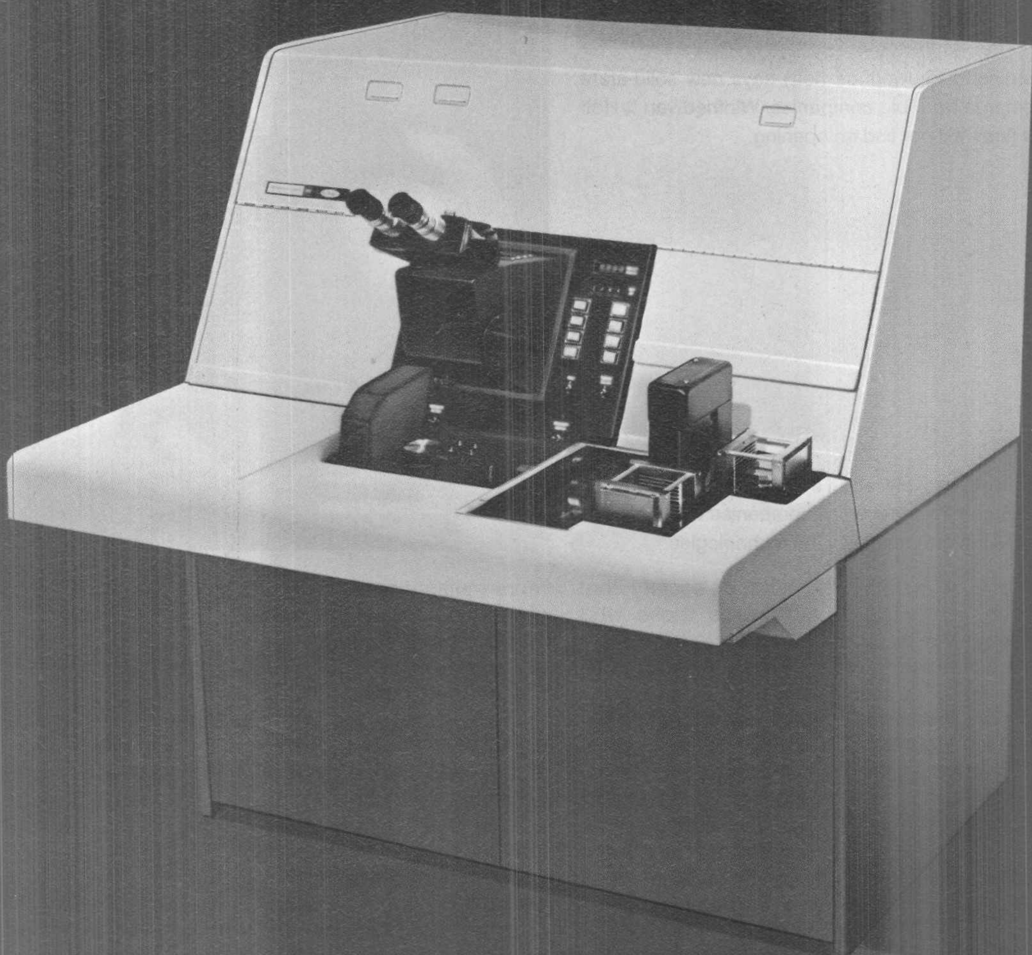
The European data-processing market is growing faster than that in the U. S., he says, and should constitute 30% of the world market by 1990. Pelissolo sees Europe shrinking the U. S. technological lead in coming years because Europe is becoming more like America in building markets that encourage innovation.

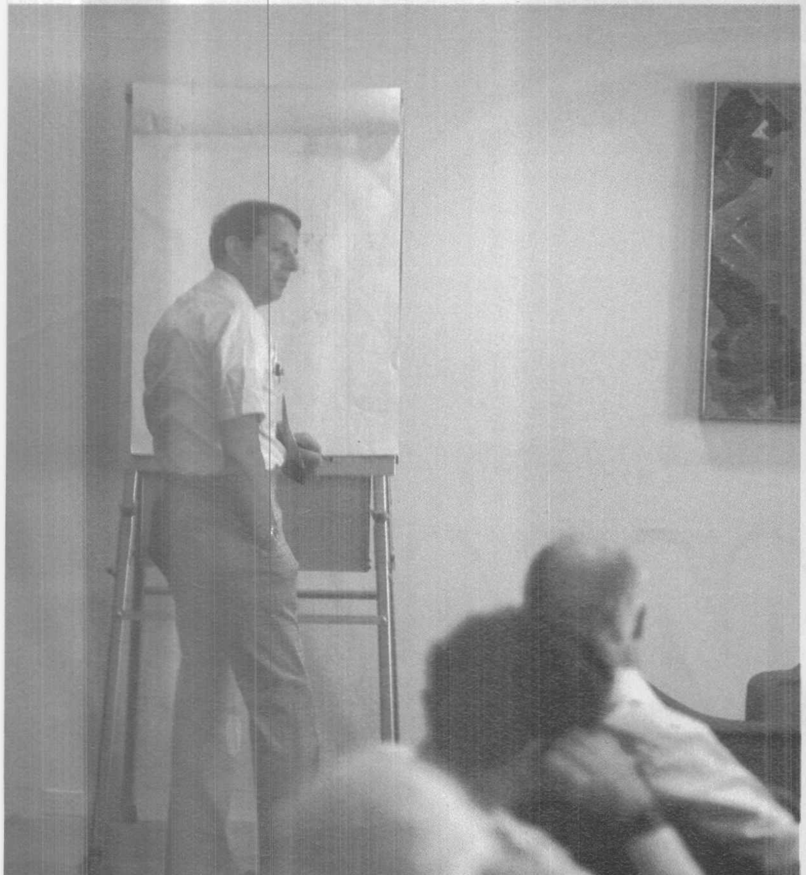
In Britain, an expert on silicon technology sees a different sort of picture for 2000. He is Derek Roberts, director of research at General Electric Co. Ltd., Britain's largest electrical company and a former managing director of Plessey Microsystems Ltd. Talking about the advances in microcircuits, he says, "The technology is running ahead of our ability to exploit it."

Though the million-device chip promises an era of runaway computer power, Roberts cautions that it is not that easy to see markets and applications for such devices that are wide enough to recover the design cost of such complex products. Also, they create a testing problem.

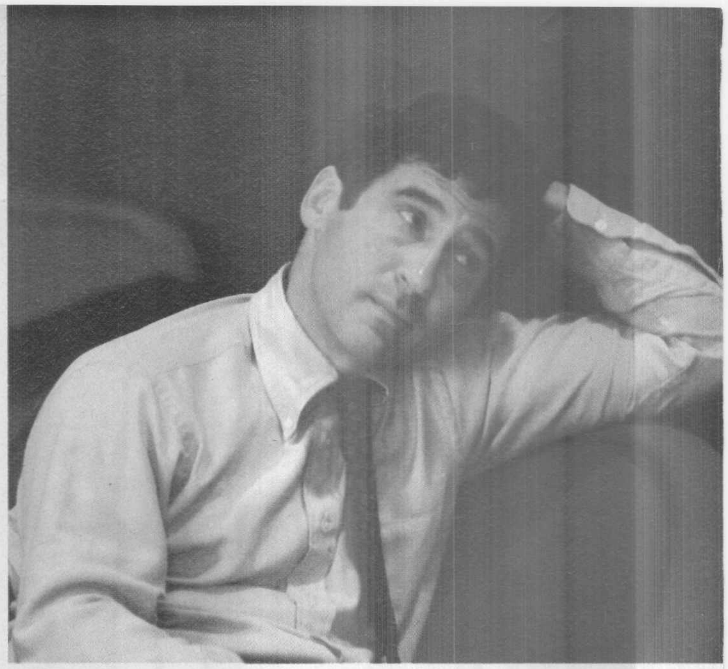
As a result, he sees the semiconductor industry polarizing in two directions. First, the traditional vendors will specialize in very large-scale integrated products, with high-volume potential "producing silicon by the square mile." Second, an increasingly significant sector of the industry will provide job-shop services for devices needed in medium- and small-scale integration.

PROJECTION MASK ALIGNER





More in less. TI's Heilmeier expects nonmilitary spread-spectrum communications to proliferate. With everyone using the entire band instead of dividing it along time or frequency lines, every school could have its own uhf channel to broadcast homework.



A new receptiveness. IBM's Gomory says the experience of getting ideas from abroad is a new one for Americans, but they had better get used to it. He says that "the pace of discovery in Europe is equal to that of the U. S., whereas it wasn't a short time ago."

tively few semiconductor companies, for example, that do not have some ownership by either a large U. S. or a large foreign systems house these days. Of itself, I see the trend as neither healthy nor unhealthy. I would like to see more independent semiconductor companies around, but that may be too much to hope for. It is getting harder and harder to start a new semiconductor company these days because the costs have risen so much in the last 10 years." The upshot, then, is that large systems houses, looking for semiconductor capability, will continue to buy into existing enterprises rather than embrace the capital risk of launching their own.

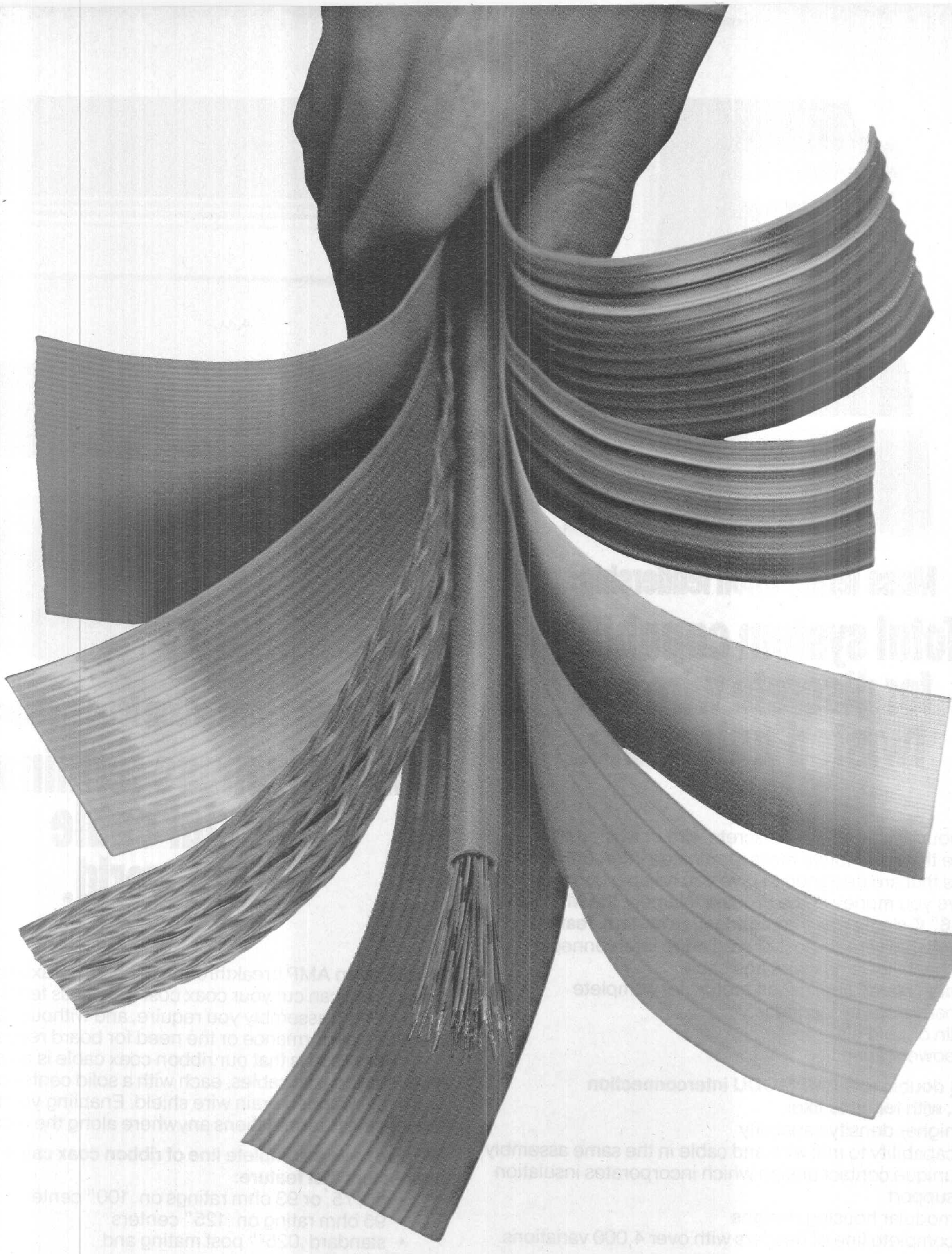
Ramo views the movement toward internationalization as a battle for technological supremacy, one that will still be going on in 2000. "Twenty years won't see completion of the contest between a free world economy, in which money and resources move freely around the world, and the isolation and protectionism of some national groups. The U. S. can at most hope to provide 50% of the technological advance over the next 20 years rather than the 90% or 95% it has become accustomed to," he says. Any new companies in the future will be set up with world marketing ambitions right from the start. "In 2000, the thinking of American companies will be required to be more international, but the idea that the U. S. is losing creativity is nonsense," he maintains.

Gomory sees as one of the important questions in the future: "How are we going to do against the Japanese? I think we do pretty well against controlled economies, but the problem is how are we going to do against another free economy like the Japanese?"

The answer, as he sees it, must take into account the difference between Japanese and American approaches to technology. "Those viewing the Japanese scene tend to see it, from a very great distance, as the degree of cooperation of the government with their various industries. But my impression is that they have very, very good engineering and that they are dedicated people who take great pride in designing good products. They simply get a lot of terribly good engineering per dollar. It's those people we're competing against, as well as the Japanese government."

Texas Instruments' George Heilmeier maintains that technology always was an international property. From the economic and marketing standpoint, internationalization may be a fairly recent phenomenon in the widespread form that we know it, he says. "From a technology standpoint, we might think today that we're seeing a diffusion of electronics know-how around the world and that represents the internationalization of technology. But that's just a part of an ongoing saga; it's been happening since the dawn of technology—it has always been international." Still, the bottom line is the same: it would appear that for electronics companies, the world will become a smaller place by the time the 21st Century is rung in.

One element in that picture that deserves more than just passing mention, says Paul Richman of Standard Microsystems, will be the role of government. "Something that will be fundamental in determining the shape of the electronics industries in the year 2000 is the relative mix of large and small companies," he says. "Also, one of the things that has resulted in the tremendous amount of progress that the industry has made over the last few years is something that is highly American, and that is the free-enterprise system and the ability of



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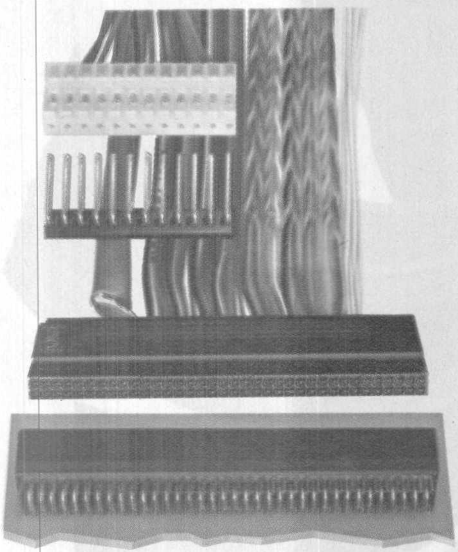

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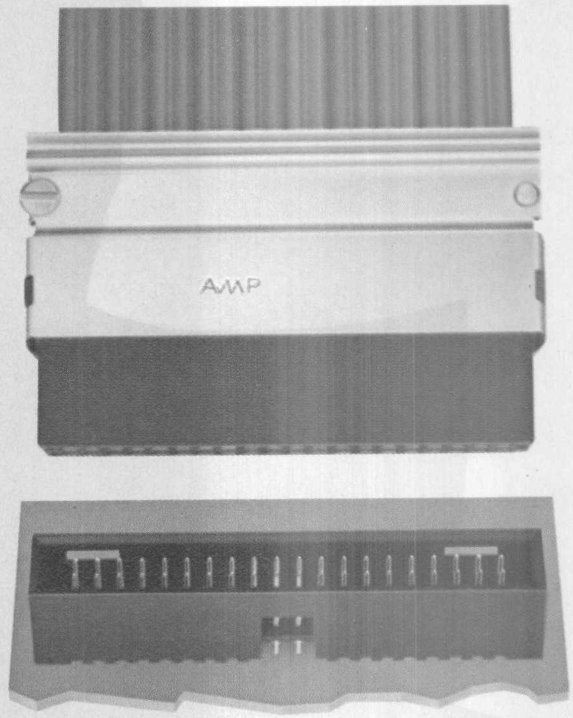

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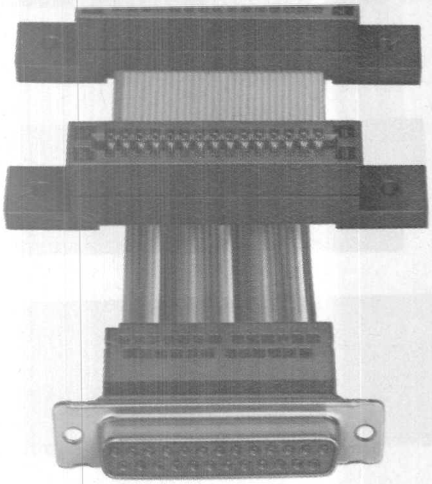

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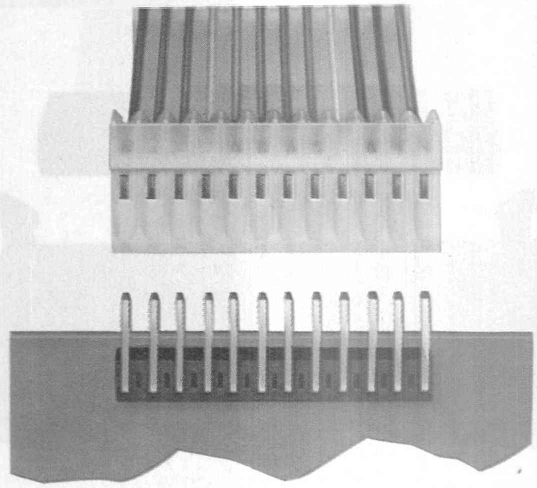

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- unique contact design which incorporates insulation support
- modular housing designs
- complete line of headers—over 4,000 variations
- compatibility with 20 to 30 AWG cable

The CHAMP connector system is also available for webbed cable applications, featuring:

- telecommunications-style housings
- wire-to-panel or wire-to-wire capability
- IEEE #488 interface
- jacketed cable and discrete wire capability

Together, these three systems give you all the capability you'll ever need in webbed cable applications. Plus the cost-effectiveness of mass termination every time you apply them.

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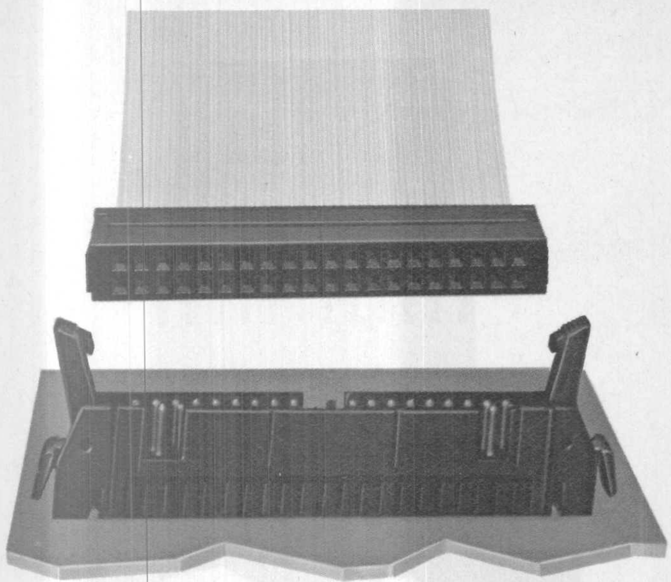

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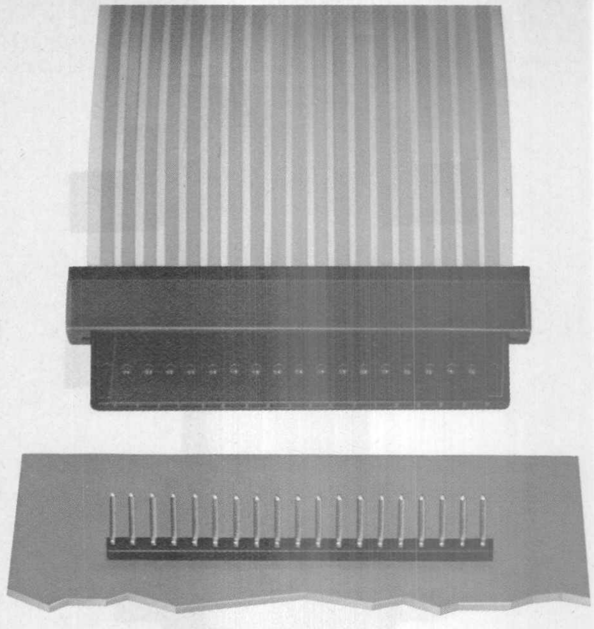
- redundant dual gold-plated spring members at the contact/post interface.
- .100" x .100" or .125" x .250" industry standard interface
- common grounding buss
- selective ground pin out with programmable application tooling that terminates in 40 seconds

The features of our connector combine to give you an assembly with more controlled impedance. And that means you've got the extra signal integrity to run higher data rates. Reliably. And with the kind of cost-effectiveness never before available.



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- conductive ink capability

Of course, we also provide all the application tooling and technical assistance you need. Or you can opt for completed FFC assemblies made by AMP. Either way, we've got a better way.

For more information on this and our other mass termination capabilities, call the Mass Termination Information Desk at (717) 780-8400. Or write us. AMP Incorporated, Harrisburg, PA 17105.

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The coming VLSI industry

One man especially well equipped to look to the year 2000 is Richard L. Petritz. A long-time electronics venture capitalist and entrepreneur, he was a principal founder of Mostek Corp. in Carrollton, Texas, which today is one of the leading semiconductor memory makers. Most recently he organized Inmos Corp., another semiconductor maker, this one with the backing of the British government. So when Petritz talks about the integrated-circuit business, everyone listens.

He maintains that what has been seen so far is just the prelude to the glittering era to come. "The real industry is just getting under way, and that's the microcomputer industry," he says. The world has finally discovered "the universal component" in the single-chip microcomputer.

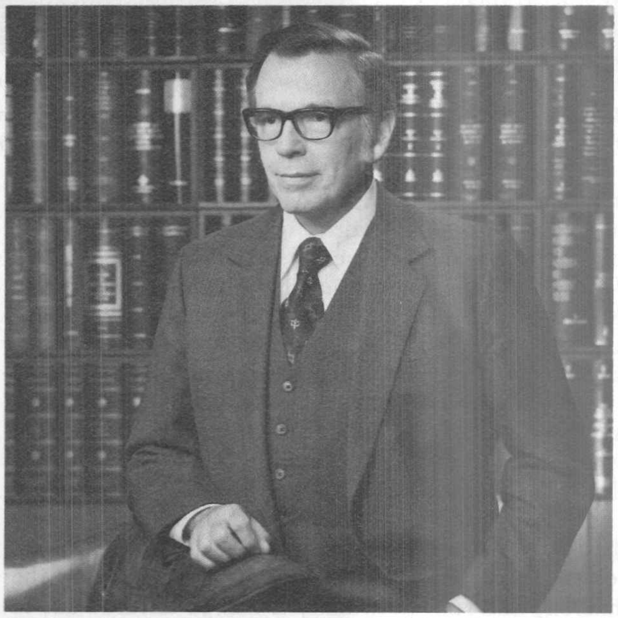
The solid-state world has gone through three ages, Petritz believes. First was the age of the transistor, a circuit component requiring engineers to specify voltages, waveforms, and other parameters. Second was the age of the IC, in which engineers worked with logic modules and the specifications of 1s and 0s instead of voltages and the like. Emerging now is the third age, that of the microcomputer, described by Petritz as a system component, requiring designers to deal basically with interfaces.

In the next two decades, the system will be the largest element that must be dealt with, he says, and "it's hard to comprehend a system that can't be implemented on silicon in a microcomputer" in that time. Demand will mean that owning a company producing very large-scale integrated circuits will be like owning an oil well, he reasons. He expects that by 2000 there will be only 10 vendor companies left worldwide, and because of capital requirements to stay in the business, they will be very large and very profitable. "There won't be any system house that will be able to afford to buy less than 50% of its VLSI requirements from those 10 outside vendors," because the volume of the vendors' sales will put them so far ahead on the VLSI learning curve. The other source of devices will be in-house divisions started or maintained by users for their own needs. But those captive operations will move out to the VLSI mainstream with specialty devices needed by the parent also.

Who will those lucky 10 vendors be? In Petritz's view, some, and maybe all of them, are around today. Some, like Texas Instruments and Motorola, will likely not be purely semiconductor houses. Some will deal exclusively in VLSI—and Petritz, naturally, counts his Inmos among those. He also predicts that a half dozen or so attempts will be made to start new companies, but these efforts will not take the traditional venture-capital route. They will be started with the kind of major backing possessed by Inmos itself or by Zilog Corp. (from Exxon).

Paradoxically, he believes that money will not be a problem: "There's plenty of it around—look at the Arabs." Instead, he feels that the critical limiting factor is people: finding entrepreneurial types who can work full time for years to put a new venture together and then staffing it with technical personnel.

At any rate, he sees 5 or 6 of his big 10 in the U. S., 2 or 3 in the Far East (and he includes South Korea as a possibility), and 2 or 3 in Europe. He expects to see the U. S. continue to supply about 50% of all technology advances: "The U. S. is not going to roll over and play dead." Being on the front edge of technology "appeals to the American ego," and since the U. S. has the people, the money, and the world's largest market, there is every reason for it to come up with half the advances.



The best is ahead. Richard Petritz says IC innovation to date is just a prelude to the excitement of the microcomputer age.

entrepreneurs to come out with products and processes and new developments spurred by the profit motive. So one of the key things is going to be government involvement over the next 20 years in the shaping of what that mix is going to be."

It is vital, says Richman, that government not tamper with the innovative cycle that starts with a small, entrepreneurial company that grows to large corporate status on the strength of innovation and creativity. "If you look at the microprocessor revolution, it came out of companies like AMD, Mostek, Intel—all small companies 10 years ago. They made major contributions. One of the main problems recently has been that the cycle has been interrupted—venture capital over the last five years has been virtually nonexistent. If we don't watch out with respect to government involvement, we may find that in the year 2000 the electronics industries will be dominated by a few major large corporations and international cartels. If that is the case, American industry will certainly be in great difficulty."

Carl Carman believes that "in the last few years, creativity hasn't had the same spark." Therefore, "if we have only 50% of the people in the world who implement technology, we'll probably have only 50% of the exploitation of that technology. What has changed those numbers is that the diffusion of technology throughout the world scientific community is so much quicker. If foreign companies can diffuse their technology faster than we can diffuse ours, then we're going to come out on the negative side. But in the end, it's not how many

Getting the work out. Standard Microsystems' Richman notes that multinational companies will probably base decisions on which countries in which to invest their resources to a great extent on the productivity of any particular nation's engineering talent pool.

points you have on the scoreboard that counts—that is, what percentage of the ideas originated where. What counts is the economic reduction of that technology."

Moore sees the international diffusion of electronic technology as inevitable. In fact, he recalls, a Japanese official speaking at Caltech once enumerated the troubles of his nation as including the relocation of much of the native textile industry to South Korea. The official even sadly predicted that one day Japanese would be driving Toyotas made in Korea. "That is a natural evolution," says Moore. "The countries that are developing are picking up the technology and entering at a fairly high level. Electronic technology will diffuse as lesser developed countries with lower labor costs pick up the technology and run. Eventually it will be diffused out to where it can be produced least expensively."

Thompson points out that such diffusion, or transfer, of technology is the best way to give foreign aid. "It's a lot easier to export, say, the textile industry than to give money. Just give them an industry."

Ramo singles out the cooperation between government and free enterprise that exists in Japan and Western Europe as a prod for the U. S. "Maybe in the next 20 years we'll manage to get rid of some of the government constraint on growth. Here, small companies can't get cash, larger ones don't have the cash flow. Our rivals overseas don't face those problems. I'm confident that by the year 2000 we'll see a trend toward government-private relationships that are superior to what is emerging from the present trend."

In any event, "a meeting such as this one in 2000 will find itself talking half the time as if there are no separate American and Japanese companies and half the time as though there are," Ramo says. "The typical company may be one that is heavily involved with investments in various countries and getting the benefits of those investments. I think many multinational corporations are that way today; it certainly is partially true of the one I know most about. So when you ask, 'How are we going to do against the Japanese?' you have to have in the back of your mind 'What do you mean by the Japanese; what do you mean by we?' "

Too often, when the pace of innovation is discussed, the role of the military is ignored, Ramo argues. Its influence on technology may have shrunk somewhat since the heady days of the 1950s and 1960s when decisions in the Pentagon charted the course of electronics. But he thinks the trend is toward a renewal of that steering power.

"In the year 2000 we will discover that military technology all over the world will be a very big factor in what happens in electronic technology. And the proliferation of nuclear technology that enables threats to the world to be made by small nations, and even by groups within nations, and the energy instability that adds to the conflict between the haves and the have-nots—all of those problems will not get solved in the short term. They create an instability that makes military strength a necessity." Ramo adds that West Germany and Japan in particular will do more militarily than they have in the recent past.

Looking back on his years at the Pentagon, Heilmeier agrees that the military and space communities lost the initiative in the 1970s. But "there's no evidence that they're going to recapture that initiative any time soon. There is a tremendous cultural barrier in the Depart-

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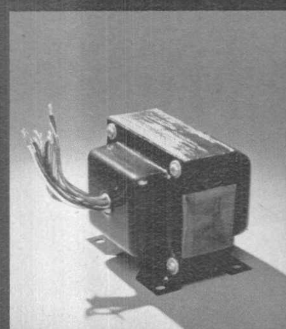
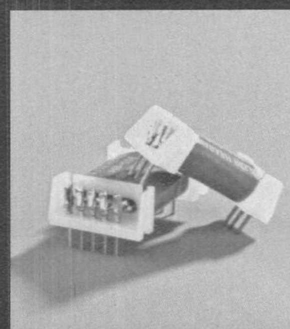
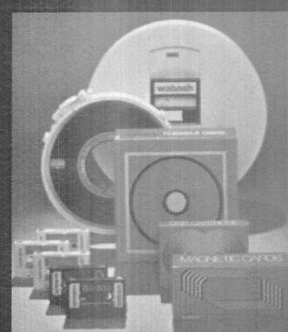

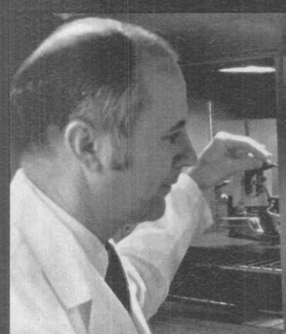

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ment of Defense to implementing the type of technology in which the U. S. leads the world: sophisticated command, control, and information-handling techniques.

"For that reason I don't think that we'll see the Department of Defense take, any time soon, a leadership role in information technology, for example. I think they'll continue to be behind the power curve. It's not really a technical problem; it's a cultural problem, and usually cultural problems get solved in large bureaucracies by traumatic events—and that's what's most disturbing to me."

Taking the concept of a cultural factor further, Gomo-

The view from the Northeast

In 2000, as now, it is likely that the information-processing industry clustered around Boston's universities will flourish. Officials at consulting firms and computer manufacturers agree that business will boom, but there are some differences of opinion on the shape of the industry.

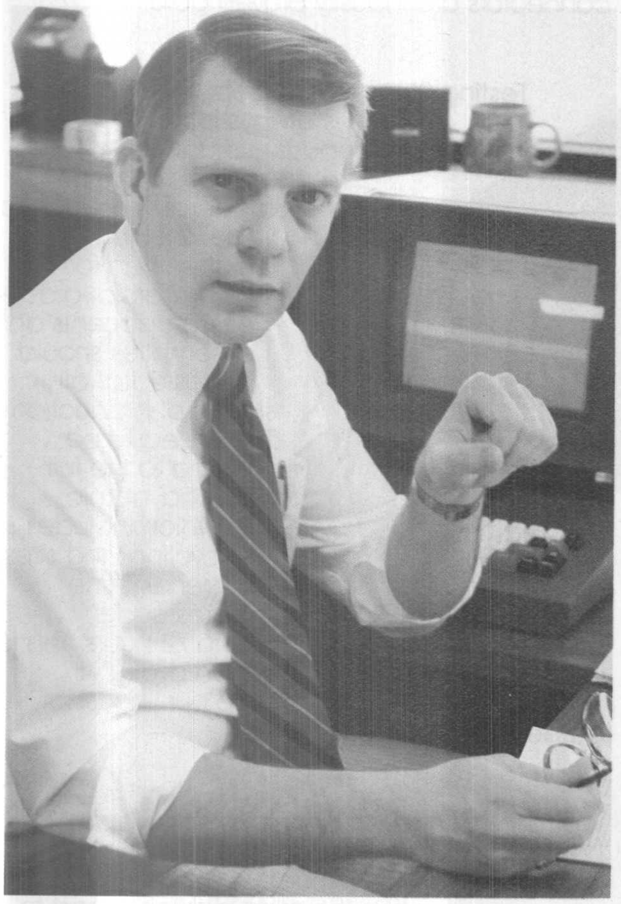
At Arthur D. Little Inc., the world-renowned consulting firm, Guy L. Fougere is a vice president and head of the physical sciences group and a director of Cambridge Consultants Ltd. in England, a Little subsidiary. He foresees a "steady increase in the number of companies appearing, rather than a decrease or conglomeration," but expects there to be fewer semiconductor startups because of the capitalization costs.

He does expect more widely distributed creativity in the next 20 years because of the advent of the microprocessor. "Products emerging from a thousand different garages and basements strike me as being very plausible in the next 10 or more years," he says. "The telephone system has what seems to be an almost magnetic attraction for these budding entrepreneurs: each socket in the wall is a market."

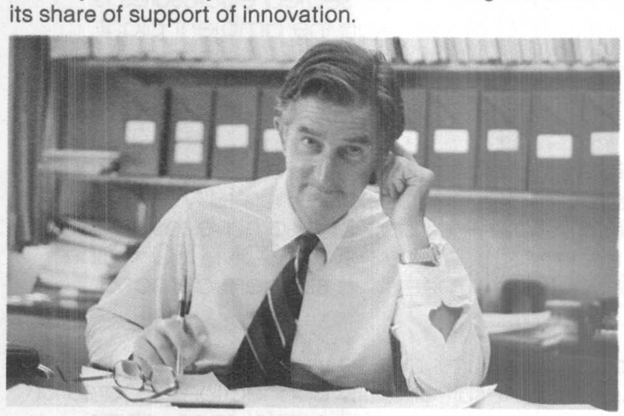
At Prime Computer Inc. in Framingham, Mass., director of research David Nelson sees few indications that there will be a great number of small companies by the time 2000 rolls around. The best prospect for a small company in the computer industry, he says, lies not in manufacturing but in the area of value-added software. In fact, he believes that software and services will draw more emphasis from both large and small companies. For the large companies, Nelson sees a great deal hanging on an upcoming legal battle over information distribution that can be summed up as IBM versus AT&T versus the U. S. government. The trend he sees there is toward deregulation of telecommunications—in fact, the Federal government would like to deregulate the area now if it could figure out how, he says.

A pair of scientists from GTE Laboratories Inc. in Waltham, Mass., vice president and director of research Paul E. Ritt Jr. and director of technology William F. Nelson, understandably have something to say about the conduct of research and development at the turn of the century. Ritt thinks the outlook for small R&D companies is not good because venture capital is tight, compared to the 1950s and 1960s when "someone with a good idea could just go down to the corner, talk to someone in a large company, and get the money he needed to bring his innovation to market."

Nelson feels that the relative percentage of U. S. contributions to R&D will decline because the rest of the world is coming up so fast. He believes that technology will be more expensive because the social and political problems it is being asked to tackle will present the need for more expensive solutions. Though industry efforts may be organized in consortium form with the Government leading the way, Nelson says, the Government will begin to reduce its share of support of innovation.



Big and small. For small companies, Prime's David Nelson sees the best opportunities in the computer industry lying in value-added software rather than traditional manufacturing.



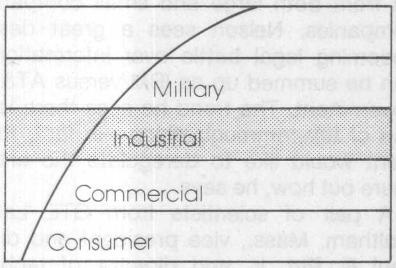
Steady growth. ADL's Guy Fougere foresees a "steady increase in the number of companies appearing, rather than a decrease or conglomeration," except in the semiconductor industry.

ENOUGH IS ENOUGH

IT'S TIME SOMEONE ESTABLISHED 'INDUSTRIAL GRADE' COMPUTER SPECS

It's Time Someone Established 'Industrial Grade' Computer Specs. Computers started in clean rooms and then moved into offices. Soon people tried to put them out in the plants where they couldn't stand up to the heat, humidity and other hostile environmental factors.

But, just because a computer is smart enough to run a machine doesn't make it an 'industrial grade' computer. Too much computer hardware that is billed as 'industrial' breaks down in the real world of the plant.



Industrial specifications for military computers are too stringent and too costly to be practical for industrial applications.

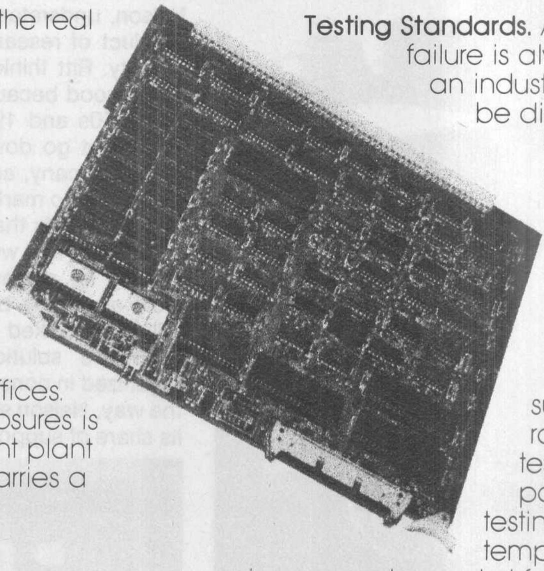
Temperature. We believe that the minumum acceptable 'industrial grade' temperature specification should be 60°C. Factories are not comfortable like offices. The temperature inside sealed enclosures is usually 15°C higher than the ambient plant temperature. XYCOM's '180 + ' line carries a 65°C specification.

Relative Humidity. In a plant, a computer should have a tolerance to relative humidity levels from 0% to 100%. They should also have resistance to condensation. The new XYCOM '180 + ' line with XYCOAT™ meets this stringent demand.

Vibration. Failures due to vibration are virtually always the result of faulty connections, boards or chips. To meet 'industrial grade' spec, chips should be soldered to the board and EPROMs clipped to their sockets. in addition, units should be subjected to 100% full vibration stress and subsequent testing to ensure maximum product integrity.

Contaminant Protection. Salts, dust, dirt and oils are enemies of computers. They even find their way into sealed cabinets in plants. The XYCOM '180 + ' line is XYCOATed to keep contaminants from the boards. (See corrosion.)

Corrosion Protection. Plants are killers when it comes to atmospheric contaminants that corrode and destroy. XYCOAT utilizes a specially formulated shield that protects module components from moisture, fungi, grease, oxidation, salt spray, acids, alkalis, and many other harmful elements. In addition, XYCOM connectors are industry proven gold.



Testing Standards. A computer failure is always bad, but in an industrial situation it can be disastrous. Testing Standards for 'industrial grade' should be higher than for 'commercial grade' All components and assemblies should be tested at all stages of production. They need to be subjected to the full range of dynamic testing which includes power cycling and stress testing under extreme temperatures under microcomputer control for up to 72 hours. This is in addition to our stress vibration cycle. All XYCOM products are tested to our 'industrial grade' standards.

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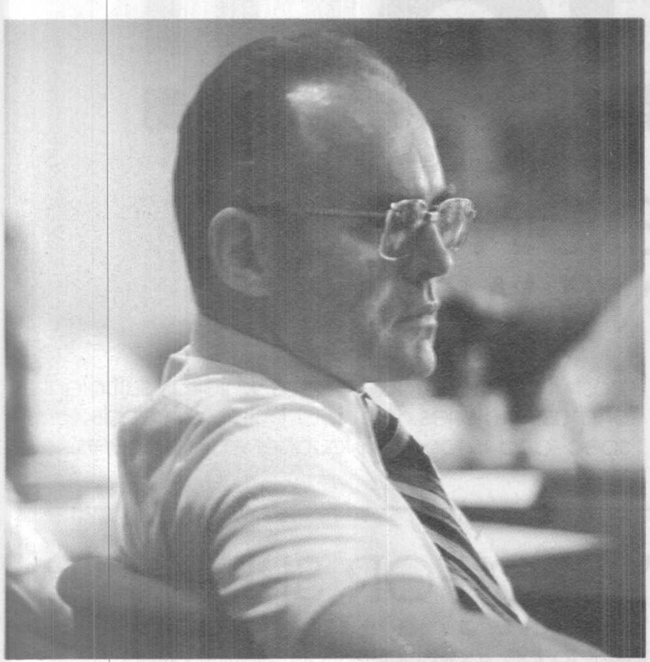


Slower movement. Intel's Moore thinks that the semiconductor industry, with more and more capital invested in it, will change more slowly. "Some of the problems associated with inertia will come into the business," he says, and it won't be able to change models fast.

ry spreads it around the world. Although he agrees that a meeting of industry thinkers in 2000 could have an international makeup, he also can foresee "very strong, nationally oriented, industries." The reason, he says, lies in the strong pull that is exerted by cultural ties and by nationalism.

Such a development could be viewed as a brake on growth or progress, but what other barriers to the evolution of the electronics industries could pop up in the next 20 years? The panelists agree that such hindrances could take the form of shortages of the properly educated and trained people, difficulties in realizing fully the advances that innovation will make possible, and poor government-business relations.

For Heilmeier, prime among the limitations is the problem of finding the people. "In the VLSI era, where will all the designers that will be required come from? And where will all the software people come from to service the 'era of computational plenty' made possible by VLSI?" Unless there is some sort of new approach, he says, some sort of innovation, the crisis is going to be over getting the trained people needed to fulfill the promise of VLSI.

Thompson returns to the problems of culture. "Without some significant change in the technological base, problems of complexity are going to create, in turn, those cultural and management problems that are going to end up stifling an awful lot of activities. I really hope that we can find some way to keep the small thing alive and vigorous because that's the only way tomorrow can be a successful tomorrow," he says.

Thompson continues: "The problem that Heilmeier attributed to the DOD is present in any large organization—and with more and more things going to be done by large organizations, I'm worried. The cultural orientation of a large multinational company frightens me. The culture of IBM, the culture of ITT, the culture of DOD—they start to become very meaningful things. It's almost as strong as the culture of being an American or being a Japanese in terms of trying to get change to happen within the organization."

By contrast, Gomory classifies himself as very optimistic on the management of innovation. "The tough part of making technical progress is on the software end, but I do think that there is a learning process. People will find a way to do it—and I think they're going to manage to go right on."

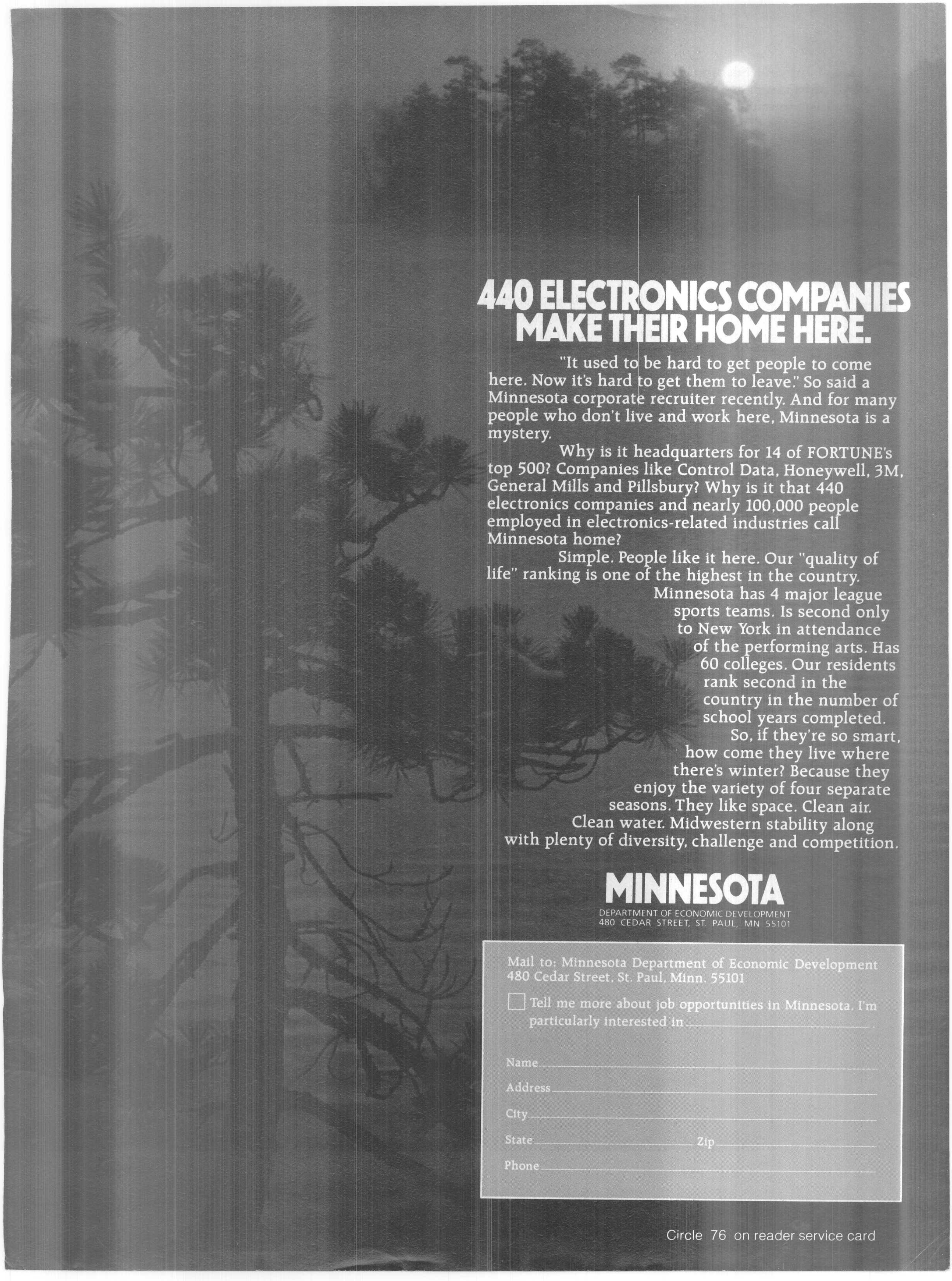
Moore sees a problem looming in the match between design resources and the super chips that must be designed. "The total number of electronic functions produced by the semiconductor industry roughly doubles every year. Project that trend for 20 years, and the limitations that you come up with are apt to be ridiculous. So design questions are a real problem."

He also sees hardware becoming more like software, with the expense of design high and the price of reproduction low. "The cost of design is increasing linearly with the complexity of design of the product," he says, "but the cost of reproducing the product is remaining essentially constant. So the software cost dominates, and the hardware cost becomes trivial. The productivity problem of software is exactly the one we're going to have to deal with in defining and designing the functions we're going to make."

Richman sees a lesson for the future in some of the problems experienced by the semiconductor manufacturers over the years. Most of these problems come in a time of "severe manufacturing overcapacity, which results from slackening user demand and overambitious plant expansion. But as we approach 2000 we may have another major problem to deal with: if the semiconductor industry does not focus its resources on the development of computer-aided-design techniques to keep up with the process development," then it might create manufacturing problems.

"The biggest limitation, particularly in America, is in government-private relationships," says Ramo. "But I'm optimistic because the nature of that limitation is going to be understood rapidly over the next few years, and innovative, economic, and international forces will be applied to it. However, while I'm optimistic about all forms of innovation, I'm least optimistic about that limitation because we have invented in the wrong direction here in America. Our response to economic, political, and social forces has been to create a confusion and a wrong trend in the proper role of government *vis à vis* the private sector, and we have been developing a hybrid of government control and a free economy that isn't the right mix."

Carman believes that if anything is going to limit advances in the next 20 years it will be human resources. But he is also worried about another form of government regulation: that coming from the courts. "If liability is going to be assigned to computers, all of a sudden a lot of the techniques we've used in the past to put out machines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are going to be very difficult to use. That will be especially so if, say, you come along with a very large-scale integrated machine and you suddenly have huge amounts of software that go out hardened and therefore you have to accept liability" because a court decides that the computer is to blame. Such a trend will significantly limit a computer company's options on how it can distribute intelligence, he says. "Maybe it will mean that we can't go to VLSI with lots of outboard or hardened functions. If we make a mistake and have liability for that mistake, we may not be able to afford to use that technique—and it has nothing to do with technology."

Laying aside the unanswerable question of whether demand will motivate technologists or technology will create demand, it is still possible to study the role that various specific electronic solutions will play. First on the list is the computer, and the prime question is what level of performance the ubiquitous machines will reach.

"We won't count in instructions per second," Gomory reckons, "we'll just be thinking in other terms. I'm sure, also, that there will be a lot more parallel processing because it will be harder to make progress in raw speed: price-performance is easier to push than speed, and I think that will push us in the long run in the direction of distributed functions."

Carman believes that, for economic reasons, a way will be found to increase computing power without forcing designers to change circuit technology. "Let's take the example where I'm in MOS or TTL and I want to double my performance. Say I accomplish it by going to emitter-coupled logic. Then all my test equipment, in the factory as well as the field, will have to be changed because of the change in circuit technology. Therefore, I will use all the techniques available to me—parallelism, multiprocessing, or whatever—to try to prevent changing the basic technology. So in 20 years we'll still be using n-MOS, or an evolutionary technology from that," he predicts.

Gomory adds that there will be big machines and small machines and that "we will gang them." But whatever is used and whatever is done will be largely invisible to the user. Agreeing that people will use computers without knowing exactly what it is they have in their hands, Heilmeier says that the big impact in the future will be made by the interface between the user and the machine. "If computers are to become pervasive, that's vital," he says.

The computer also must become easier to use if it is to become the universal tool that some observers predict. Heilmeier says that first "people must be able to interact with the machine on their terms, rather than vice versa. We're going to be deluged with data, and people will want to extract information from that data—but they're not going to want to memorize protocols or data-base structures or anything of the sort. The sophistication of the machine is not going to be in the trivial amount of computation needed to get the answer, it will be in organizing the data to do that trivial computation."

Gomory holds that one "increasingly do-able" technique will have the computer generating an image that shows what the user would see if he or she were looking at ledger sheets. In fact, he sees no reason why the top of a desk could not some day be a giant display, with "piles" of certain papers in one corner and others "stacked" elsewhere.

Information for all. With computers becoming more pervasive, Carman would not be surprised to see them generate a new utility—he calls it an information-bank utility—in which national data banks would spread information via satellite and rooftop antennas.

Moore wonders if, by 2000, it will be possible to use conversational English to communicate with a data base or with an automated typewriter. Richman is convinced that such a thing will come to pass. However, he believes that progress will be made not so much in the industrial sector as in the home. "You're going to see computers there with speech-recognition capability and speech-synthesis capability. You may even see personal computers evolving to the point where they're actually hand-held or like a wristwatch, so that you can carry around your bank book or even your medical records."

There will be a great deal more voice input, says Heilmeier. However, he adds, "general speech recognition, unconstrained speech where it's not speaker-specific, is quite a ways off."

Gomory agrees: "Unconstrained speech with any speaker and some background noise is very hard to do. However, I'm not sure it matters that much, because before you come to that you can go through so many gradations of constrained speech. It is relatively easy to get, say, 95% or maybe 98% of the words right—but to get from 98% to 100%, which is what you need if you want to dictate a letter to a typewriter, really is the difficult thing."

Whether or not computers will be able to carry on useful conversations with the world at large, Carman believes that they may generate a new utility, one that he dubs an information-bank utility. Here, information would reside in a large national data bank and will be

Light talk

With the world turning into the information society, dissemination of speech and data will become even more crucial. That is the view of the scientist generally credited with being one of the fathers of fiber-optic communications, Charles K. Kao of International Telephone and Telegraph Corp.

Tough fiber. Charles Kao believes that fiber-optic communication will be the ideal method for handling the coming information explosion.

To handle all that data, he says, "we already have developed the means of processing it, but we will need a more efficient transmission medium. That medium is fiber optics." Kao, a 46-year-old British-educated scientist, has been with ITT for more than 20 years and now works in the firm's Roanoke, Va., facility. He started work on fiber optics in 1964 and published his first paper on the subject two years later, in 1966.

More complex electronic circuits will be required to manipulate, store, and process information, but the use of fiber optics—"it will be all over the place"—will not directly affect circuit design, says Kao. "However, by 2000 the terminal will be more complex and the central switching office will be radically different," he adds.

He also foresees a "separate packet-switching network for data because it is much faster than voice: 1-millisecond segments versus segments of perhaps three minutes for voice. Fiber optics will become cheaper and cheaper, though it will not replace copper completely—"after all, copper can conduct electricity," he notes.

disseminated via satellite and rooftop antennas.

But how will all these computers, both visible and transparent, in the factory and at home, be built? Will VLSI make it possible for designers to use a wide range of architectures for their computers? No, says Heilmeier. To be sure, he says, there will be more than one architecture, but the extreme—"where everyone has his own architect—is not going to happen."

However, the key element in the eyes of Carman will not be hardware or architecture but software. "It would be interesting to be able to have different machines that run on standard software," he says. Heilmeier's feeling is that software will continue to develop along familiar paths, "but I see a much more extensive use of nonprocedural languages." His definition of such languages is that they tell a computer what to do, not how to do it. Today's languages tell both.

Such a change would also alter the relationships of designer and programmer. "In the future," he says, "the role of the programmer may be to create a formalism or structure by which the system engineer can interact directly with the computer" instead of using the programmer as a go-between. "The system engineer will input the rules of the game, and the programmer will give him the structure by which he can do that. That may be one of the ways we can get around the bottleneck that looms in software development."

The only way this will come to pass, he says, is another cultural revolution, a radical change from the first 30 years of the computer's history in which the programmer was constantly exhorted to write software that used as little memory hardware as possible. As the software bottleneck becomes more restrictive, "people might say, 'I'm spending too much money on this front-end process—if you guys want to use 30% more memory, go right ahead'."

Ramo believes that the tremendous investment in already installed technology will preclude major changeovers to new and better equipment. "Our own Government, the biggest user of computers, is using computers that are out of date so badly that if you could imagine buying up-to-date ones, it would save so much money that in a very short time it would more than make back the cost," he says. However, the American political system is one that favors expediency over such farsightedness, he adds.

As for the general populace's acceptance of computers, none of the electronics executives sees any problems—not even with questions of invasion of privacy. Carman says the tradeoffs will tip the balance in favor of computers. Referring to TRW's credit-verification services, Ramo says, "We have found that if someone wants more privacy, we can do it more easily by applying technology than by limiting the application of technology. There are concerns, but the way to meet the concerns is to do the right job with the technology and not to look at it as a limitation."

Summing up, Gomory says, "One thing we can say is that by the year 2000 a very sizable slice of the population will be comfortable with computers."

Much of the future structure of the electronics industries will depend on the shape of the information explosion, a phenomenon nurtured by electronic technology. Communications is the key, since in recent years its costs have become the greatest component of computing expense.

An important consideration, says Thompson, is whether the communications network will link individuals to computers or computer users to each other. As one of the small band trying to study the future seriously, he has applied his vocation as a communications engineer to his avocation as a futurist—and he sees two possible scenarios for the information explosion.

His first he calls the every-man-an-island scenario. "It is essentially a downplaying of the concept of networks. One might expect an increased use of broadband. And


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Defense comes back. TRW's Ramo gestures toward the military and his expectation that it will regain some of its former influence on the shape and direction of technology. It is his opinion that West Germany and Japan will become more active than they have been recently.

there would be a lot of stand-alone memory for processing in the home—it wouldn't be a case of which 10 channels but of which 500. This scenario will evolve if we move in the direction of working for short-term economic benefits."

Thompson's alternative is what he calls the every-man-a-node scenario. "It is conditioned on being able to deal with the constraints which seem to be forcing us to use this new computer-communications technology in ways that predominantly appear to be extensions of industrial technology." That task accomplished, "I would expect to see evolve a network that has some very interesting highly intelligent characteristics in terms of interfacing with the user. The network would start to exhibit the kind of properties that would make it seem aware of the context of the traffic it's handling."

An example of such a network, he says, is the modern computer-aided learning system. Here, the path a student takes through the material is given some kind of mathematical definition, letting the computer respond to the student's responses. Moreover, for students taking the same paths, the system sets up communications links between them. Thus individuals are linked automatically on the basis of the activities in which they are engaged.

Such a system would be about the only way to move toward an information society with two kinds of characteristics, says Thompson. "The first is that information can be meaningfully evaluated, integrated, and synthesized within the network directly." In other words, no surrogates would be necessary: a computer model of an IC would also tell the designer whether the circuit would work—he or she would not have to build one. The second characteristic is present already: information is treated as a private economic good that can be traded like any other commodity.

The problem is, says Thompson, that unless there is some sort of payoff for looking at the long-term significance of such an alternative, short-term expediency "will move us toward the every-man-an-island scenario with considerable haste. So I'm not completely optimistic about the every-man-a-node scenario. This kind of intelligent network is really essential if we're going to get that kind of convivial entrepreneurship and if we're going to deal with the information explosion that is going to result from it."

To tell which way society and the technology are going, he says, watch to see if the broadband approach, delivering many TV channels and the like, gains ascendancy. Also, "one would expect to see an increase in paranoia," he says, "as it would become necessary to engage in sharp practices to continue to win the right to have a significant role in such a society. So you can expect that if encryption devices for telephones start to become a common product, we are on our way to the first scenario." Thompson says he sees emerging a value set that indicates people are moving that way.

On the other hand, Heilmeier believes that both scenarios will come to pass. "If you want to get a

At a crossroad. Bell-Northern's Thompson points to two directions for communications: broadband for short-term gains, or an emphasis on "intelligent characteristics in terms of interfacing." But, based on present tendencies, he expects the former to predominate.

broadband link to everyone," he says, "one of the routes is to do that in a guided mode—and look at the impact of fiber optics. If you want to do that in the unguided mode, look at the impact of very large antennas in space—adaptive antennas. The day is not far off, if it isn't already here, when we'll be able to put a very, very high-gain adaptive antenna in space. And you'll be able to think about everybody having a small satellite antenna on the roof." The technology to do that will surely be here by 2000, he adds.

But Thompson is holding out for more than a mere ability to see and hear someone or something else on a display. "What I really want to do is find someone I don't know about whose ideas happen to have some resonance with my ideas. The network should be smart enough to say, 'You guys are doing similar things and ought to get together.' That is, my telephone number should be more than just my address—it should be my interest profile, my behavioral use of information, and that kind of thing."

Ramo, turning to what he calls the more mundane aspects of communications in 2000, remarks that the basic vehicle for electronic information exchange already exists—the telephone network—even if it will be some time before it is ready to meet the full demands of the computer age. "It will take 20 years for AT&T, the French, the Germans to take even today's technology and make it available," he says. So by 2000 "we will have begun to use digital techniques extensively and we will have installed the infrastructure for it. Most of the time, if we want to communicate, we will just pick up the phone as we do today."

Heilmeier predicts a three-legged stool of fiber optics, large adaptive antennas in space, and—a new development—nonmilitary spread-spectrum communications instead of frequency- and time-division multiplexing modes. In the future, he believes, this kind of scheme, where with proper coding everyone uses the entire band instead of dividing it along time or frequency lines, could result in "lots of different users residing in the same band." For example, every school could have its own ultrahigh-frequency channel with a radius of, say, three miles around the school, and if every child had a book-sized TV set, homework could be sent over this channel. What will make such communications happen, he adds, is surface-acoustic-wave technology married to integrated circuits.

But a smothering influence on that kind of progress, says Richman, is the Federal Communications Commission. "The role of the FCC will have to change," he says. "Computers, semiconductors, and so on have made giant strides because they are unregulated. But the FCC as it is now structured is the biggest obstacle to such progress."

If one development can be singled out as the seminal electronic invention of the past 50 years, it would be the semiconductor. Advances in design, fabrication, and application of the devices since they first appeared seem to be unending—but how long can that continue? For


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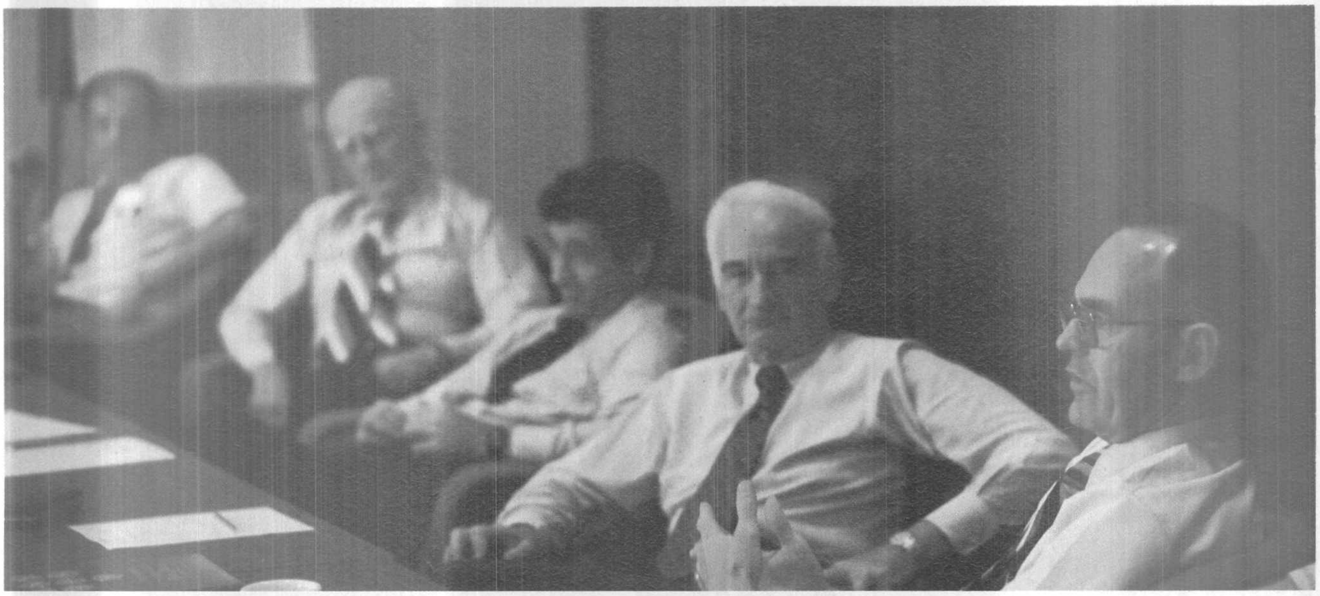

Wrapping things up. Fellow panelists listen as Intel's Moore says that device packages of 2000 will not change. The world will continue to operate on a 5-volt standard, he believes, because a change to a 1.5-V standard would mean huge costs for new ancillary equipment.

there is a growing school of thought that the rest of this century may see semiconductors reach their physical limits: for example, highly concentrated electric fields with submicrometer structures. However, the history of technology is seeded with examples of apparent barriers reached and then breached by new approaches in design or material.

Heilmeier notes various intermediate barriers in MOS technology—in patterning, design, and interconnection, for example. If these are overcome, some people expect problems when channel lengths reach 0.2 micrometer because of oxide integrity, he says. But Moore maintains that silicon will still be the main material, though it may "sit on other substrates."

More to the point, says Heilmeier, is the still broad potential for semiconductors. For example, he expects by 2000 to see high-temperature superconductors "accessible to liquid helium or liquid nitrogen." Moreover, he says, the IC business does not get very far from the surface—"we're basically a two-dimensional world"—so someone might get smart and might exploit the third dimension. In addition, what would happen, he asks, "if we learned how to passivate the surface of compound semiconductors?"

Then there is design automation. Heilmeier believes that "we will have a new concept that will be much more deeply rooted in machine intelligence and image understanding than the current systems are." He also expects there to be more mixed-material chips—for example, devices made of silicon and gallium arsenide—more knowledge about defects, increased use of energy beams in fabrication, a true nonvolatile random-access memory, and solid-state technology applied to solar energy. And, he adds, "I won't rest until we have a book-sized solid-state TV."

Focusing on the semiconductor industry itself, Moore foresees a tremendous amount of evolutionary improvement taking place—but with the industry becoming more capital-intensive, such movement will occur more and more slowly than in the past. He also sees "some of the problems associated with inertia coming into the business." As the semiconductor industry becomes a larger part of the total economy, "we get sunken investments, we can't change models much faster than the auto industry can, and that kind of thing."

Conceding that there still will be a great many advances, Richman also says semiconductors are moving from a revolutionary to an evolutionary mode. Still, he adds, "we are going to see a lot of advances that look evolutionary but are really revolutionary." He heartily seconds Heilmeier's motion of use of the third dimension to build devices. "We're seeing it already in things like V-groove MOS; we're seeing double poly and triple poly; in the static RAM area we're seeing high-resistivity polysilicon folded on top of the active transistors to increase the density in respect to RAM size."

Look also for multilayer silicon structures, with the multilayers containing active components, he advises. In random-access memories, or RAMs, there will be increased evolution in processes. For example, titanium silicide and molybdenum silicide have "all the advantages of polysilicon, but offer lower sheet resistivity," he says. Also, gallium arsenide devices are finding more and more proponents.

With all this, though, Carman believes that "the number of things we can get on a chip will continue to outpace the ability of systems to implement them." For his part, Gomory points out that though "things can continue to be made tinier and tinier," they must be evaluated from the system level. Looming here are such limitations on bit rates as packages and the problem of power in, heat out, he points out. Speaking of packages, Moore says they can not be changed because that would require monumental change. "It's a 5-volt world," he insists, "and to change to 1.5 V would mean that the whole world would have to change." □

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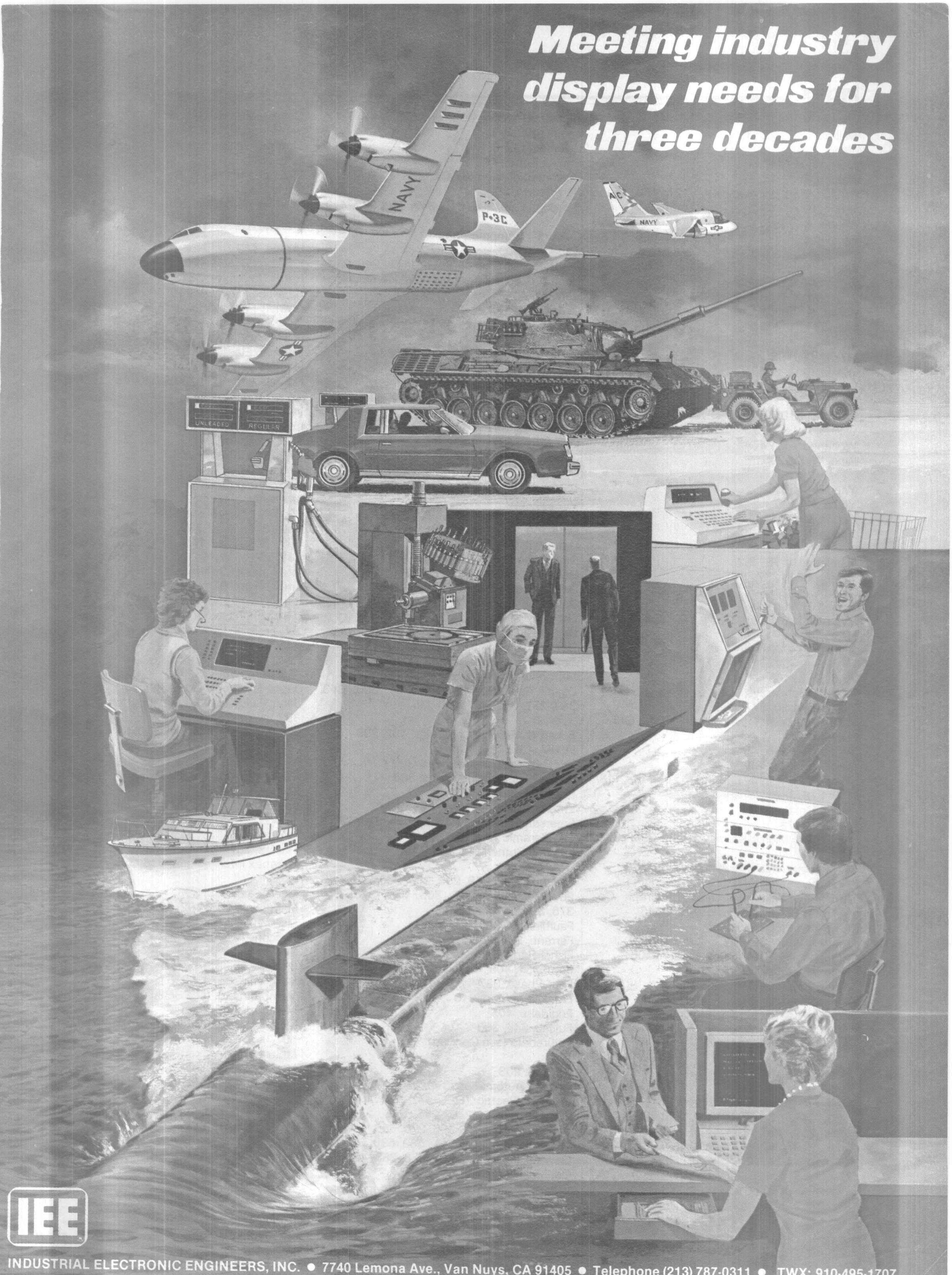
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